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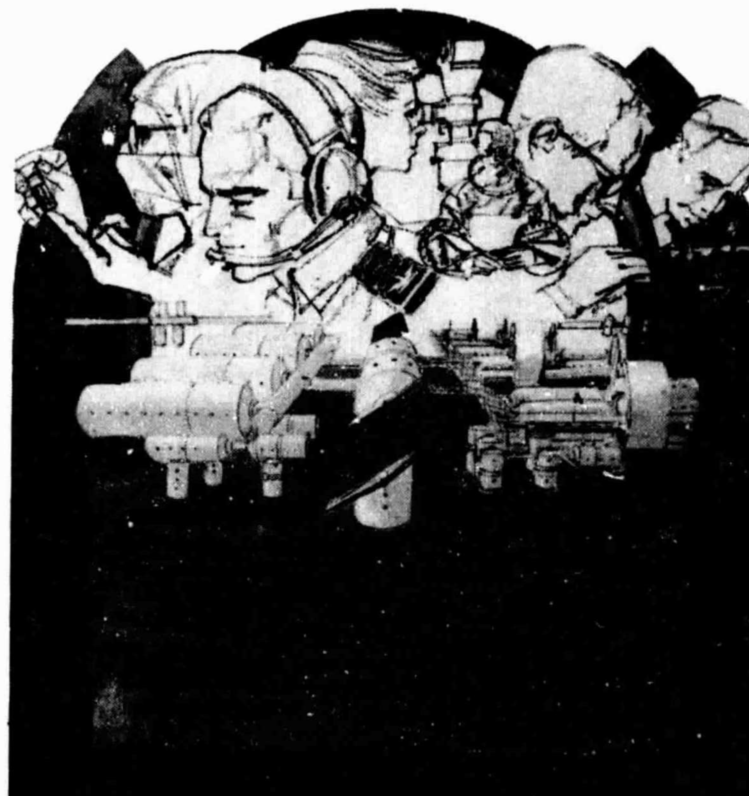
A STUDY OF SPACE STATION NEEDS, ATTRIBUTES & ARCHITECTURAL OPTIONS

Final Briefing



GENERAL DYNAMICS

Convair Division

Contract No. NASW 3682

A STUDY OF SPACE STATION NEEDS, ATTRIBUTES & ARCHITECTURAL OPTIONS

Final Briefing

5 April 1983

Presented to
National Aeronautics and
Space Administration

GENERAL DYNAMICS
Convair Division

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SPACE STATION NEEDS, ATTRIBUTES & ARCHITECTURAL OPTIONS
Final Briefing

AGENDA

Summary of Major Study Activities & Results — **Otto Steinbronn**

- Introduction & Summary
- Mission Identification & Assessment
- Mission Implementation
- Cost, Benefits & Programmatics

Space Station Program Observations — **Don Charhut**

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INTRODUCTION & SUMMARY

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The organization of the General Dynamics management team for this Space Station Needs, Attributes and Architectural Options study is shown on the facing page. The study tasks have been grouped into three major areas: 1) Space Station Utilization, 2) Technical Integration, and 3) Planning. In addition, a special assistant was assigned to assure an effective interface with the DoD community.

A Space Station Advisory Board was also set up which reviewed the progress of work and the conclusions reached prior to each NASA review. This review activity proved to be a significant benefit to our study.

Four subcontractors supported General Dynamics on this study as shown on the chart. Space Communications Company (SPACECOM) provided major inputs in the area of commercial communication spacecraft and related technology, and on how a Space Station would enhance this thriving business. Advanced Technologies Inc. was responsible for all activities related to life sciences experimentation, development and processes. They also provided major support in the area of life support systems. Science Applications Inc. provided support in the area of national security and in the preparation of our "Space Station Prospectus". Finally, Spar Aerospace Limited provided significant advice in the area of remote manipulator systems and their potential application to Space Station systems.

STUDY TEAM ORGANIZATION

SPACE STATION PROJECT MANAGER
Otto Steinbronn

SPECIAL ASSISTANT — DoD
L.R. Norris

SPACE STATION ADVISORY BOARD

Dr. J.P. Waszczak, (Chairman)
Dr. J.R. Arnold
Dr. K.A. Ehricke
Dr. B.J. Bluth
Dr. K.P. Heiss
Dr. A.M. Lovelace

Subcontractors

- **Spacecom**
  Communications Systems
- **Advanced Technologies, Inc.**
  Life Sciences/Life Support
- **Science Applications, Inc.**
  National Security Missions
  User Prospectus
- **SPAR Aerospace Limited**
  Remote Manipulator Systems

UTILIZATION MANAGER
W.G. Hardy

Develop mission requirements for NASA, civil & DoD use of a space station (Task 3.1)

TECHNICAL INTEGRATION MANAGER
J.G. Bodle

Develop realistic system architectural options & hardware implementation plans (Task 3.2)

PLANNING MANAGER
R.E. Bradley

Provide parametric cost & programmatic analyses of various elements & program scenarios (Task 3.3)

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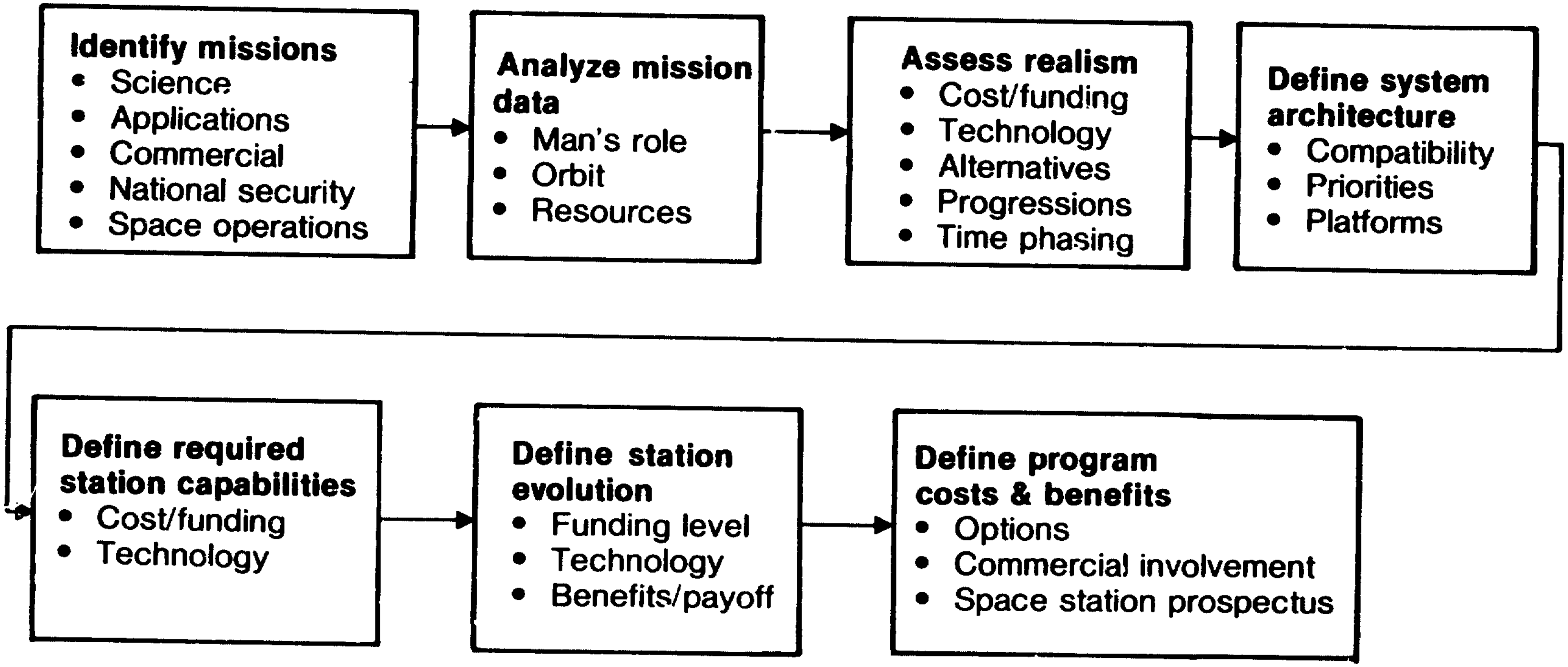
Seven major steps were involved within our study logic to identify and analyze mission requirements, define and assess potential architectural and evolutionary approaches, and to define ROM costs, economic benefits, and evolutionary program concepts. The significant aspects addressed within each step are identified on the chart.

This presentation will address each of these steps in sequence, highlighting the major activities and principal conclusions reached in each area.

SPACE STATION STUDY LOGIC



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As a first major conclusion, we are convinced that the mission requirements data we have collected during this study provides a sound basis for definition of a Space Station system architecture, evolutionary approach, and the required Space Station capabilities.

Secondly, our study shows that the development of a research, development and production facility with an IOC in 1990, which is augmented by an operations and servicing capability starting in 1992, is the appropriate first step in a Space Station development program. This conclusion is clearly supported by the "baseline mission set" which we have developed.

Our study also indicates that all missions which prefer a 57° orbit inclination, can be accommodated either in 28.5° or 90° orbits, or are suitable as free flyers. Consequently the need for a 57° Space Station is not supported by the baseline mission set.

With regard to a polar orbit station, limited requirements (7 missions) do exist for a polar station late in the next decade (1998-2000). However, these requirements are limited and not yet fully mature. Consequently, it is our conclusion that implementation of this station should be delayed until the end of the next decade.

MAJOR STUDY CONCLUSIONS

1. Mission requirements exist that are adequate & representative for station definition

2. From a priority standpoint, the initial space station to be developed should be a joint research, development, production, operations & servicing facility at 28.5-deg inclination (IOC 1990)

3. The mission set does not substantiate the need for a space station in a 57-deg orbit in the 1990s

4. Although earlier requirements do exist, delay of a polar orbit station to at least the end of the next decade is recommended

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We have carried out a study to determine if research and development activities can be carried out in parallel with operations and servicing activities on the same station. Our study has concluded that although some level of interference will exist, the associated complications and costs do not justify the delta cost of two separate stations.

From an economic standpoint, our study clearly shows that the most extensive and quantifiable economic benefit of a Space Station is the OTV launch capability. Over 1 billion dollars per year can be saved relative to the average cost of transporting spacecraft to geostationary orbit by present launch systems. For this reason, an OTV launch capability should be developed on the Space Station as rapidly as technology allows. This technology development should be finalized on the initial research, development and production station during the early 1990's.

A ROM cost estimate was carried out to define the estimated cost of the 28.5° station at IOC, and with full capability. Based on available cost models, we have estimated the initial cost of the station to be 5.5 billion dollars (1984$). The delta cost to extend this station to its full capability as a research, development and production facility is estimated to be $800M, leading to a total estimated cost of $6.3B for this facility.

A cost estimate has also been carried out to define the incremental cost of adding the operations and servicing capability to the initial RD&P facility. This capability, which includes maintenance, servicing,and operational facilities for 2 orbit transfer vehicles, is estimated to cost $3.2B.($1984)

Finally, our study indicates that realistic opportunities do exist for private investment in Space Station development. The potential economic benefits of an OTV launch capability, and satellite servicing, provide the major profit potentials. The obtaining of significant private funds early in the development program will be difficult, but in the longer term it is considered that very significant investment potential does exist. A potential investment scheme is outlined in our "Space Station Prospectus" which has been prepared in parallel with our main study activities.

MAJOR STUDY CONCLUSIONS (continued)

5. Operations & science/application missions can coexist on the same 28.5-deg station

6. A space-based OTV launch capability is the major quantifiable economic justification for a space station ($1.1B per year) — capability should be developed as rapidly as technology allows

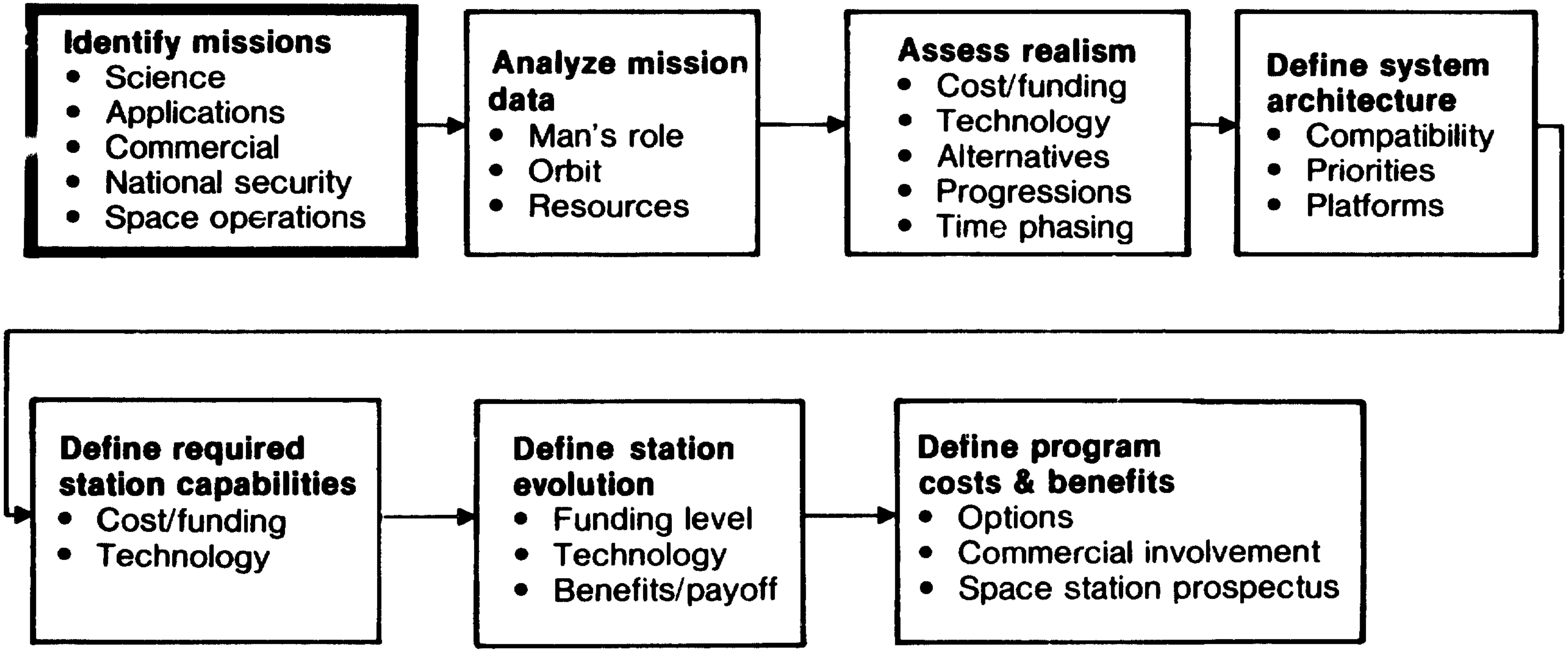
7. Cost of the initial recommended space station research, development & production facility is approximately $5.5B at IOC & $6.3B at full capability (1984 $)

8. The space-based OTV function incremental cost is approximately $3.2B (1984 $)

9. Realistic opportunities exist for private investment in space tation development — a potential investment scheme is outlined in our "Space Station Prospectus"

The next section of our briefing will present our approach to identification of appropriate missions to be flown on a Space Station. Sources of data, including potential commercial users, are discussed, and our finally selected "total mission set" is defined.

SPACE STATION STUDY LOGIC



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The mission analysis study orientation briefing of 15 September 1982 and supplements of November 1982 and January 1983 were used as the basis for many user requirements. A number of additional reports from previous NASA studies were used to expand the requirements in specific areas. For example, the MSFC Nominal Mission Model, Revision 6, was used for mission definition and schedule information.

Visits were made to various NASA Centers, universities and other potential users to gather information and anticipated Space Station applications. These visits were also used to validate mission data. For example, Astrophysics missions were validated by visits to MSFC and Los Alamos National Lab. Earth and Planetary Exploration missions were validated in the scientific area by visits to JPL and inputs from universities. Oil company contacts were used to validate the data for commercial applications of earth observations. Environmental observations missions were validated by visits to MSFC and a utility company for commercial use. Life Sciences missions were discussed with numerous NASA centers and universities. Materials Processing missions were validated by visits to MSFC and a number of discussions with commercial firms.

Our subcontractors provided support by evaluating source data, defining payload elements and validating the requirements. Advanced Technology, Inc., was heavily involved in our Life Sciences effort and made visits as well. SPACECOM assisted in developing the communications missions and conferred with a number of satellite users, such as American Satellite to validate the data.

We have received reports from MBB/ERNO and Dornier Systems which provide insight into potential European Space Station missions. Dornier's work is concentrated in the life sciences and life support development areas. MBB/ERNO has identified missions in the materials processing, life science, earth observations, astronomy, communications and space operations fields. Most of the missions are in the first two areas. A comparison of the missions and their characteristics such as size, mass, pointing requirements, power levels and data rates discloses that most are similar to those derived for U.S. missions. Some missions have similar objectives but are sized differently.

DATA SOURCES

Orientation briefing & supplements

Prior study outputs, for example

- Space platform payload data, MSFC
- SOC study
- Science & applications requirements for space station
- Spacelab mission definition

Visits/discussions

- NASA centers — HQ, ARC, JPL, JSC, MSFC
- Los Alamos National Laboratory
- Department of Agriculture
- Remote Sensing Conference
- American Physiological Society
- DoD — SAC, SD-JSC, TAC

Subcontractors

- Spacecom, Inc. — communication satellite industry
- Advanced Technologies — life science, life support systems

International

- MBB/Erno — material sciences, life science, space science, space technology
- Dornier Systems — life science, human physiology & medicine, life support systems

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We developed a Space Station User Brochure to convey to potential users the opportunities and attributes of a manned Space Station. The brochure detailed the potential technological and economic benefits of such a station plus offering a concise summary of America's current and planned space activities.

Enclosed with the brochure is a "User Fact Sheet", designed so the user can reply with an indication of their economic interest, as well as a technical definition of their potential needs in terms of size, weight, orbit, crew requirements, etc. The sheet was structured so the recipient can respond by simply checking the applicable answers, with additional space provided for more detailed answers if they wish.

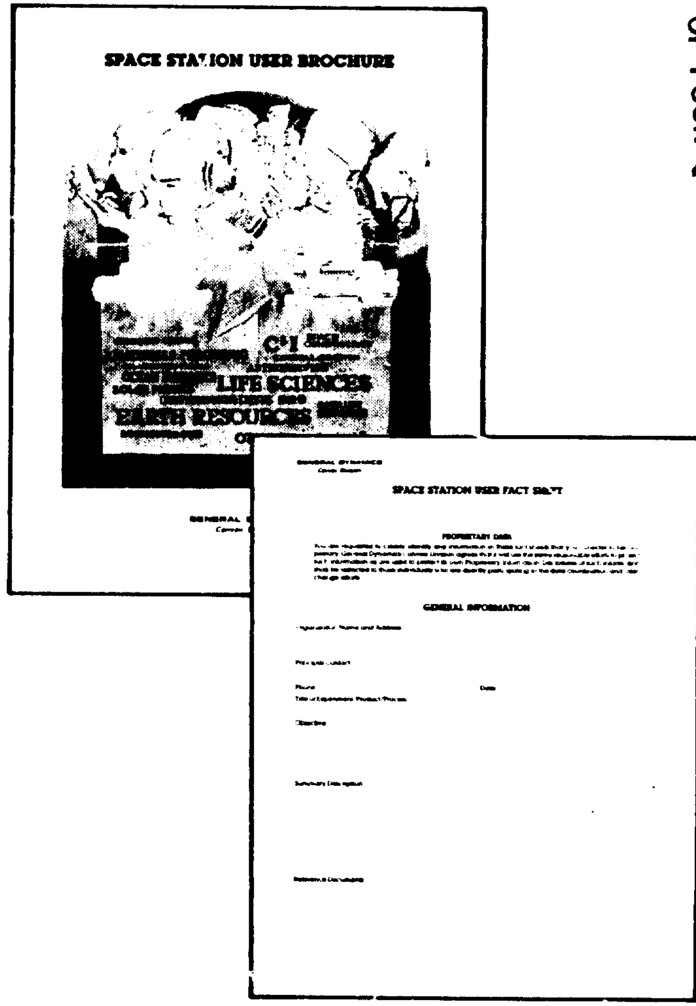
The brochures, which were offered after personal contacts were made with potential users and a positive interest expressed, provided an excellent medium for increasing interest in a Space Station program. Many of the commercial firms with positive interest want to make use of technology developed in space programs, others want to provide equipment or services to future programs and the other 25-30% are potential users. The discussions resulted in a number of mission descriptions. However, many potential users were not prepared to provide detailed technical payload element data such as NASA investigators are accustomed to seeing. Based on our contacts and discussions with commercial firms during this study, and the level of response to our user brochure, we conclude that considerable time, perhaps 2-3 years in some cases, will be required to develop the potential user market to a level commenserate with a mission definition and commitment existing today in scientific areas.

USER CONTACTS

General Dynamics Convair user brochure
- Station opportunities

User fact sheets
- Economic & planning factors
- Technical factors

Personal contacts & mailings
- 201 commercial firms indicated interest
- 40 written replies
  - Metals & nonmetals
  - Chemicals
  - Pharmaceuticals
  - Equipment
  - Petroleum
  - Foods & forestry
  - Communications
  - Aerospace
  - Electronics
  - Instruments
  - Utilities
- 36 universities — 8 replies
- 91 life science organizations — 13 replies



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The data received to date is very positive from the communication satellite sector. There is obviously an expanding market for placement of communication satellites. Satellite makers and users also expressed interest in technology development missions.

There are strong signs of interest in MPS and more limited in the earth/ocean observations sectors. Although we would have liked to have had more user input in these areas, the inputs we received were specific and of good quality. Many users of Landsat type data are very interested in continued use of such data and in advanced developments, but do not feel themselves qualified to define potential Space Station missions or payload elements.

We also found some firms who desired to be providers of equipment and industrial services and supplied specific inputs.

We feel that although present planning is somewhat inhibited by the perceived barriers, a stronger reason for the limited interests may be due to the basic nature of businesses. Key barriers are investment level, investment horizon, and uncertainty of the Government's commitment.

Special incentives may be necessary to encourage Space Station users. Based upon our inputs, potential incentives such as continued Government R&D, reduced STS costs, tax provisions and non-monetary cost Shuttle flights will be needed to expand commercial user interest.

We feel the potential market exists and can be developed, but it will take additional time. Furthermore, once a Space Station is in being, the activities therein will generate uses and users that are not or cannot be foreseen at this time.

COMMERCIAL APPLICATIONS
Conclusions

Strong communication satellite placement market exists

Promising commercial applications identified

- Petroleum & mineral location
- Remote atmospheric sensing
- Crystal growth
- Electrophoresis (continuous flow, isoelectric focusing)
- Communications technology
- Agriculture, acreage & production

Potential providers of industrial services identified

Commercial market potential & interests exist

- Planning somewhat inhibited by perceived barriers
  - Relatively long ROI horizons
  - Space operations are costly & high-risk
- Additional time & detailed discussions required to expand beyond currently identified level

Special incentives may be required to induce commercial firms to increase research investments

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Two basic categories of missions were established: man-operated which are accommodated directly on the Space Station, i.e. attached, and free flyers which are separate entities. Man's role in the mission was used as the basic evaluation criterion. Therefore, in those cases where his involvement was vital to the mission or would enhance the mission by a significant contribution on a continuing basis were classed as attached. Periodic servicing or reconfiguration is also required for many free flyers. A total of 149 missions were identified and payload element data sheets were prepared for each of the 99 missions assigned to the man-operated facility. 18% could be accommodated as free flyers. Of the 50 free-flyer missions, 54% are compatible with a platform.

The following definitions for mission classes were extracted from a draft of the Space Station Program Description Document, Book 1:

Class 1. Missions best accomplished using the manned element of the system (Space Station).

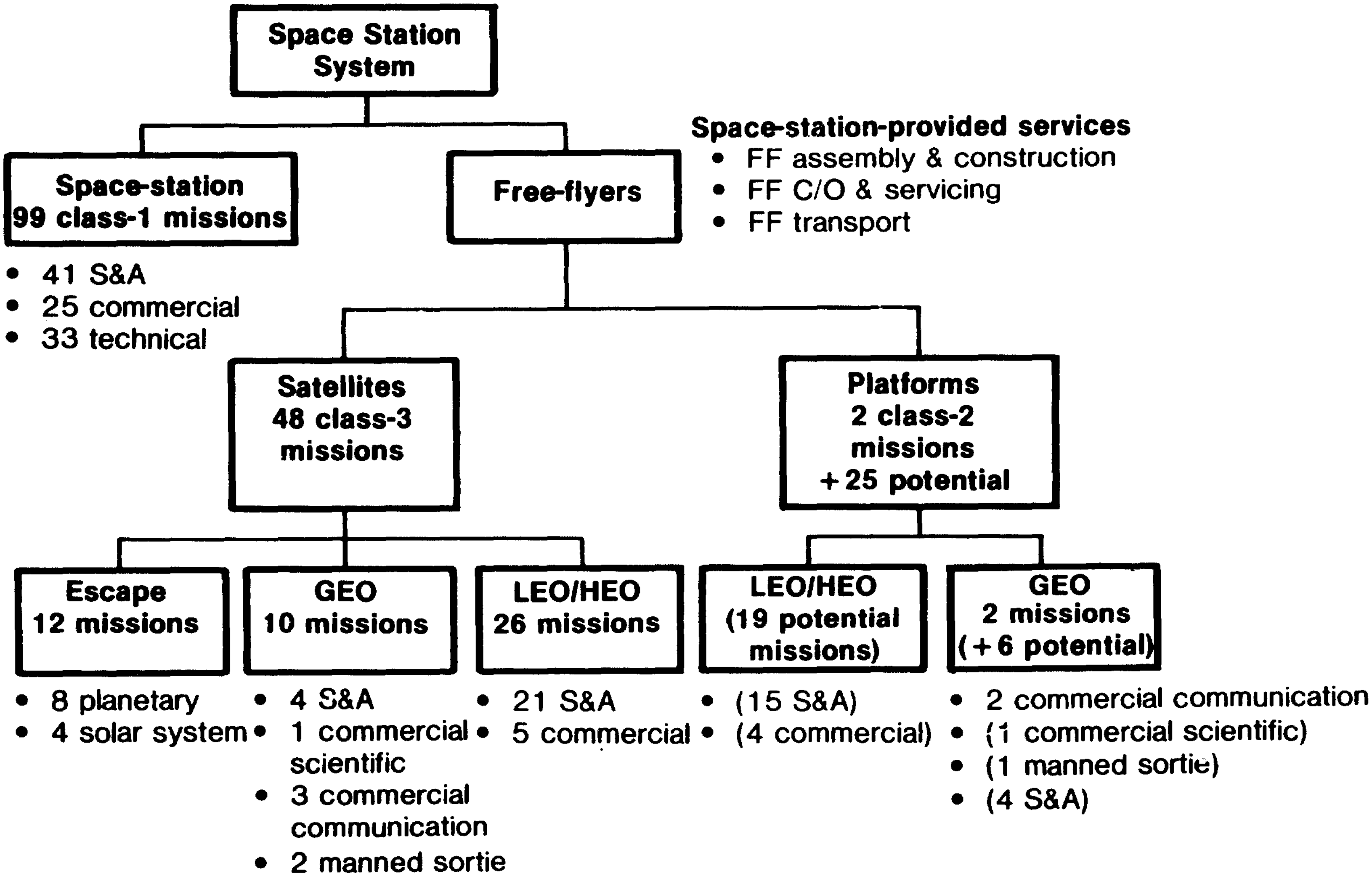
Class 2. Missions best accomplished using large, man-tended platforms (space platform).

Class 3. Missions best accomplished using narrowly focused, relatively small satellites (free flyers)

In addition, the following support services to be supplied by the Space Station to free flyers were identified:

Assembly and Construction
Checkout and Service (including Reconfiguring)
Transportation

TOTAL MISSION SET SPACE STATION SYSTEM



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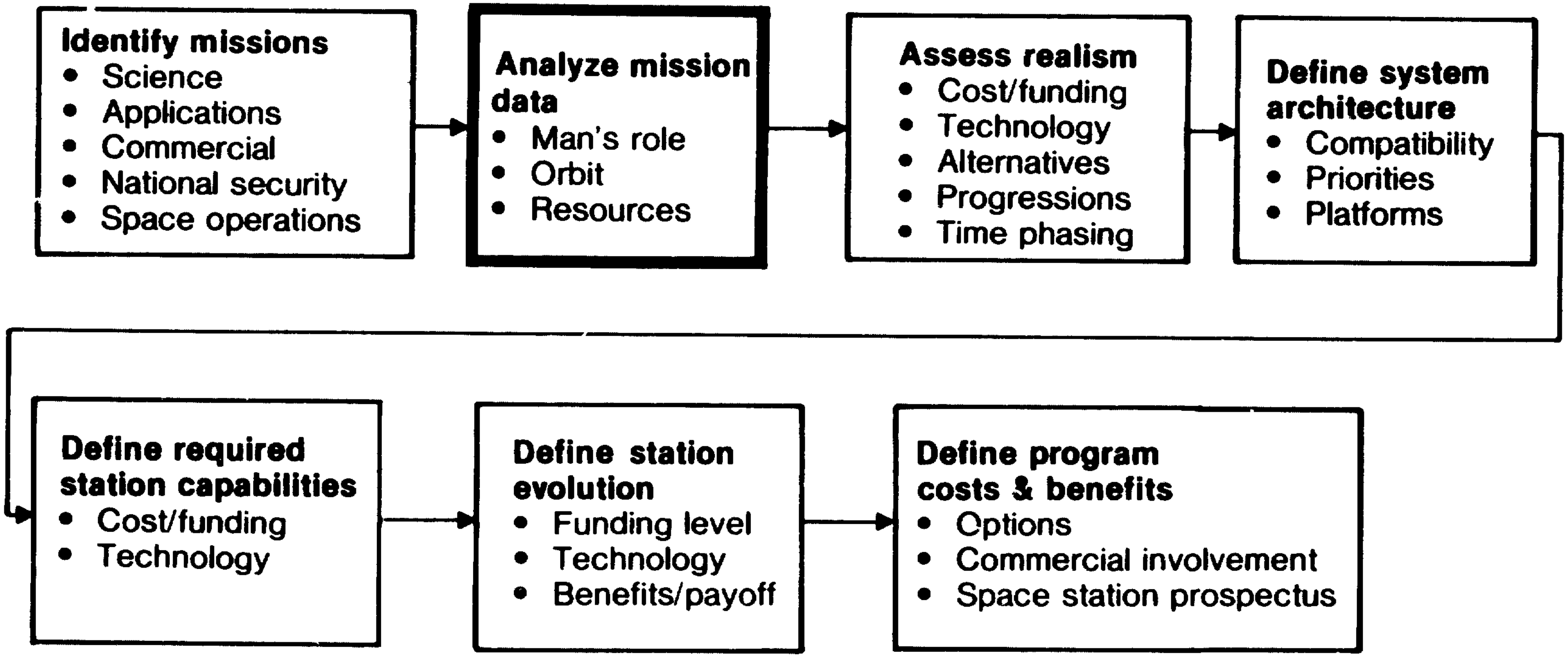
Following identification of our "total mission set", we performed an extensive analysis to define all the major requirements for each mission, such as man's role, crew size, orbit requirements, time schedule, power and data rate requirements, etc. This activity covered both Space Station missions and free flyers. This activity is discussed in the subsequent section.

SPACE STATION STUDY LOGIC



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During the Mission Definition activity it was necessary to make an initial appraisal of whether the mission would be operated in a manned or a free flyer mode to be able to define the physical aspects of the mission. This was iterated during the integration activity along with several other mission analyses. The results were fed back into the mission descriptions. The first most important part of the integration analysis was to divide the mission set into the two basic types, attached and free flying. From that point on they were treated differently because of the differences in Space Station roles.

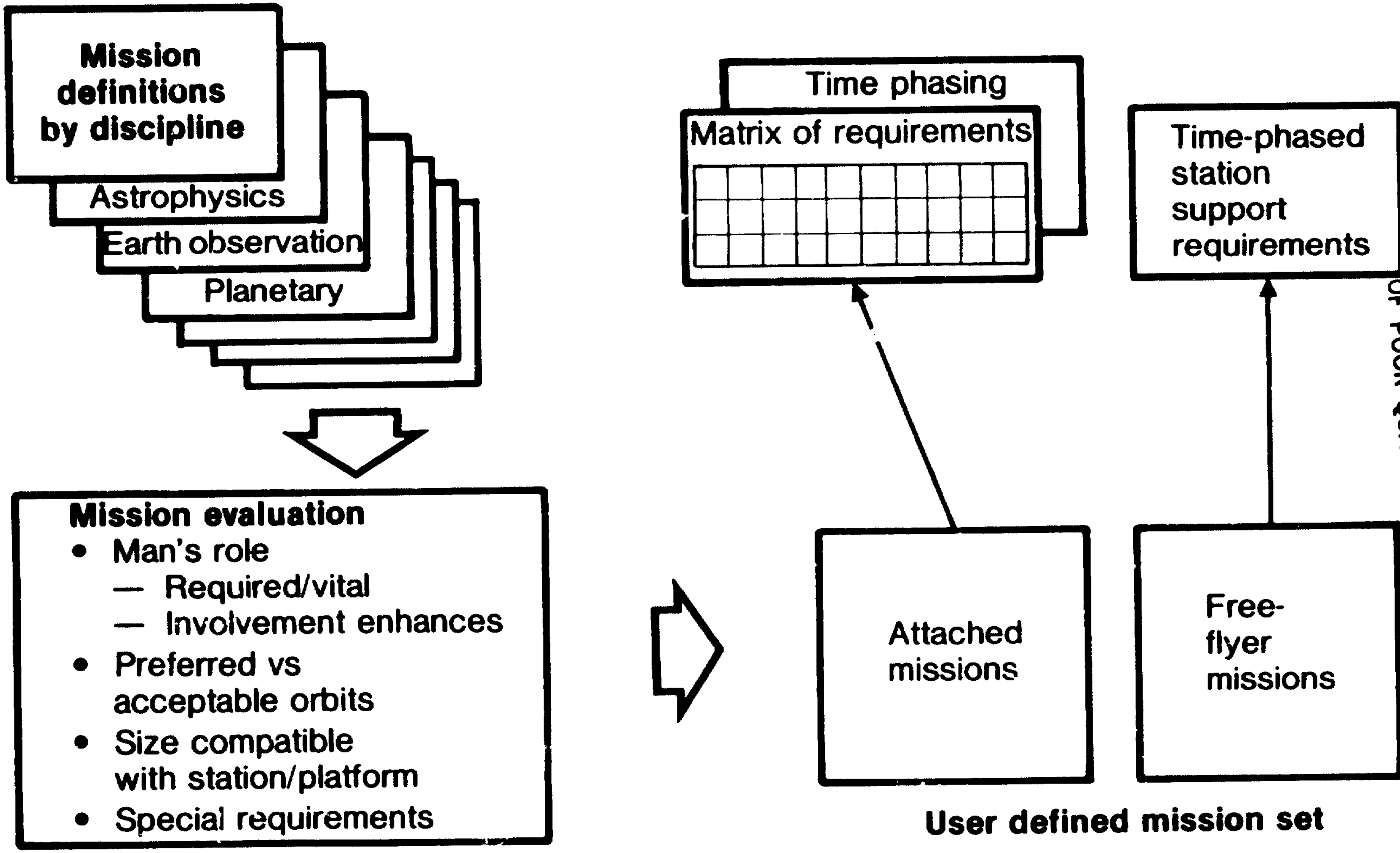
The determination for attached vs. free flyer accommodation is straight-forward for most missions, but in some cases it is not so obvious. Therefore, additional analyses and tradeoffs were performed. Some of these tradeoff studies were concerned with the operation of the mission vs. the operation of the station and their compatibility. Another was the ability to design the payload equipment for greater utility and cost-effectiveness for assembly at the station, for installation in the station, or as a free flyer. Another was to examine manual vs. automated operation of the mission in the modes needed for greatest experimental value to the scientist. Evaluation of EVA activities during assembly and later to support the vehicle were made.

For attached or station accommodated missions, the most important need is to determine time-phased station resource requirements. The principal requirements are power levels, crew size, pressurized volume, size of externally mounted equipment and data rates.

For free flyers, it is not meaningful to sum or integrate requirements for power, data or equipment sizes. The important considerations are those related to mission support by the station in terms of: assembly/construction, emplacement, service, reconfiguration and retrieval.

The purpose of these data is to provide a basis for architectural options studies to determine the type, location and general size of Space Station elements.

INTEGRATION OF REQUIREMENTS



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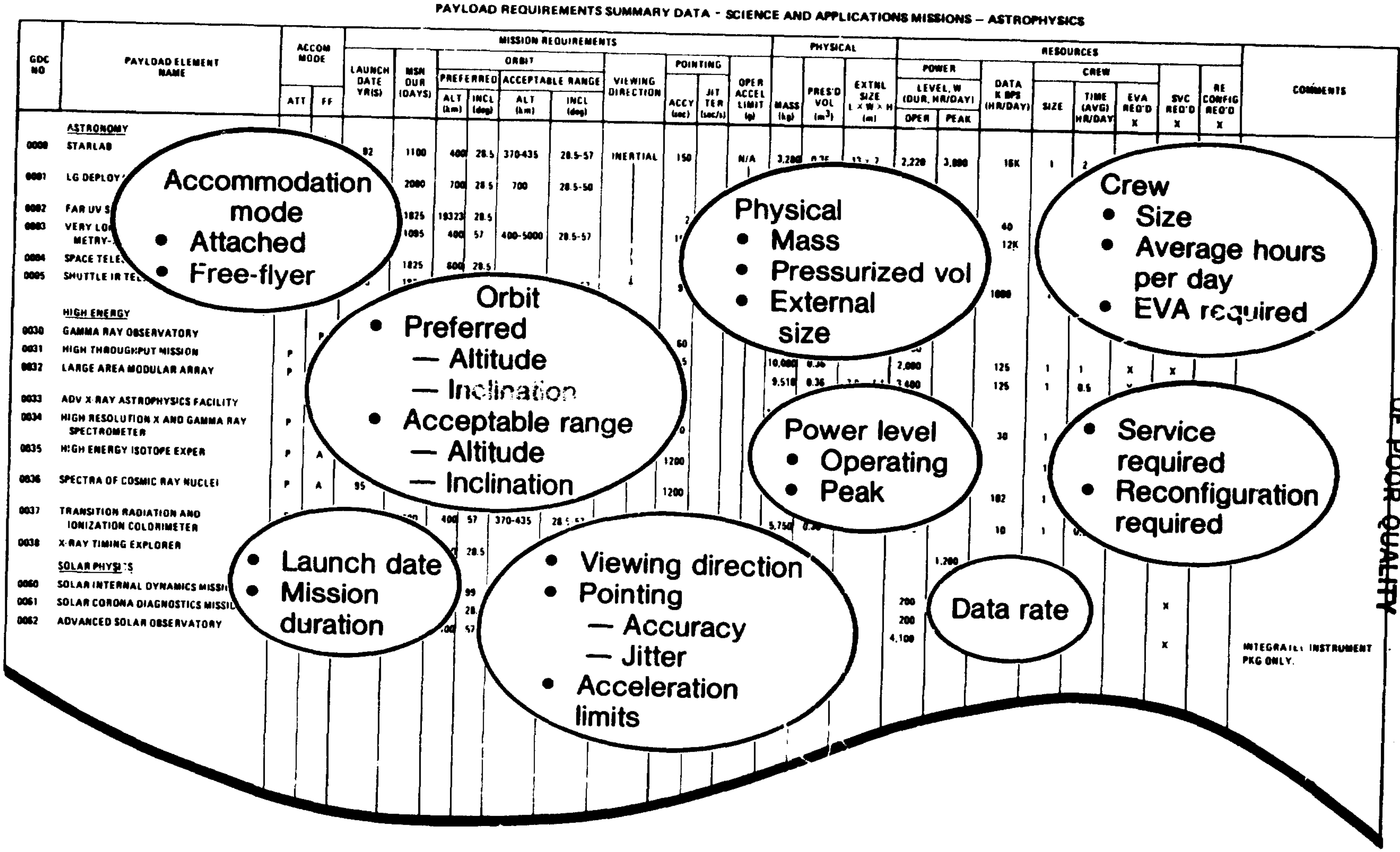
Payload requirements summary data sheets were compiled and organized originally by discipline to display the data items most frequently needed for accommodation analyses. After the integration analyses were completed, these same data were organized for the Station, i.e., man-operated mission set. Time phasing charts were also created. These summary data sheets are employed extensively throughout the architectural option study activities. Most of the data item parameters and their units were taken directly from the NASA data base format. Several entries were added to assist in the accommodation analyses.

The data sheets summarize the principle characteristics of the payload element. The first launch data and mission duration provide an easy reference for the time phasing. The acceptable orbit ranges for both altitude and inclination provide flexibility for the architectural and accommodation analyses. The preferred orbit is always used, if possible. Pointing requirements for direction and accuracy/stability as they reflect onto the station as interface requirements must be accounted for. Those missions with severe pointing accuracy/stability requirements must provide their own pointing equipment as the station's capabilities are limited by the realities of a large platform. Physical requirements in terms of mass, pressurized volume and the number and size of externally mounted equipment are also important. Key parameters are power level (both average and peak) and crew (size and average hours per day). Data rates are specified. A notation for EVA, service and reconfiguration requirements is an aid to understanding the missions requirements. The details for these are provided elsewhere.

MISSION REQUIREMENTS MATRIX



The principle types support provided to free-flyer missions by the Space Station are: emplacement into operation which may include assembly and construction as well as transportation to the operational orbit; service for resupply and replenishment; reconfiguration, i.e., of sensors; and retrieval or de-orbit to avoid long term build-up of inoperable hardware in space.

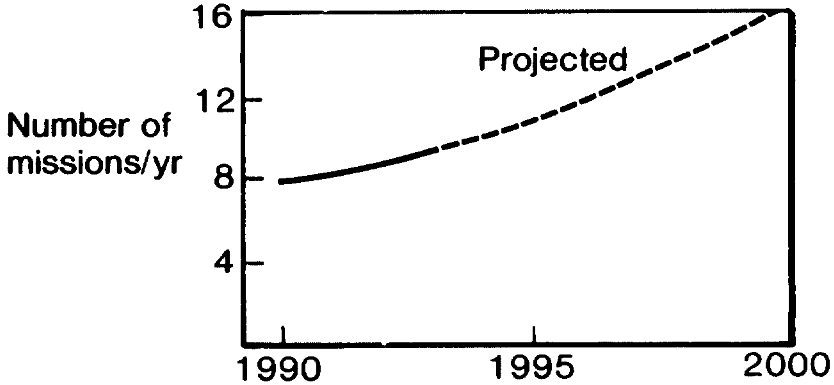
These service requirements have been segregated for LEO/HEO missions into the three principle orbit inclinations of low (28.5°), mid (57° or thereabouts) and high (near polar).

In reviewing the traffic level over the decade, we felt the "planning horizon" problem was again influencing the data. There is a higher level of activity early in the decade than there is later. One would, in general, expect the opposite. An indication that users see more clearly needs within the near term than in the far term. We feel that as techniques and capabilities are proven in the early years, planning and provisions for the use of servicing will increase in the out years. The upcoming Solar Max Repair Mission should do much to improve confidence in on-orbit repair and servicing. The data reflects planned servicing actions only. Necessary unplanned maintenance actions will increase the traffic, especially in the out years which are expected to have a larger accumulation of on-orbit free flyers. For this reason, we chose to make a projection of needs in the out years as a basis for the servicing implementation analysis and use the mission data for the early years because it is considered to be more realistic.

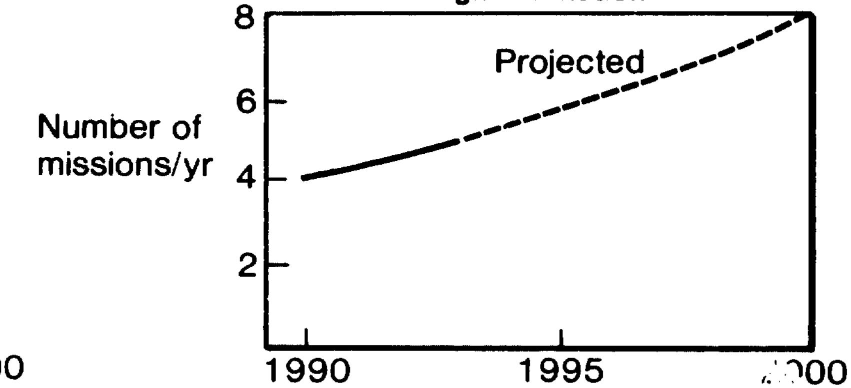
Communication satellites make up almost all the geosynchronous emplacement traffic. The results of seven principle traffic projections were compared and two separate analyses made by our subcontractor, SPACECOM. The averages per year from these were compared and near coincidence existed. In addition, the traffic estimates for the first half of the decade were compared to a previous GDC analysis and close agreement found.

STATION SUPPORT REQUIREMENTS FREE-FLYER MISSIONS
Excludes DoD

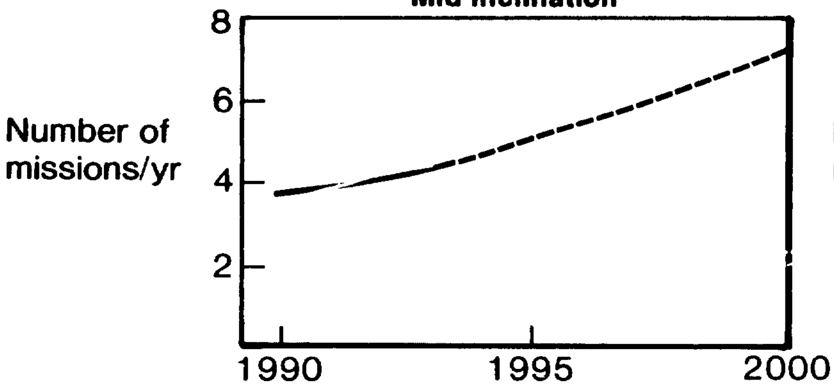
LEO/HEO
Emplacement/servicing/retrieval
Low inclination



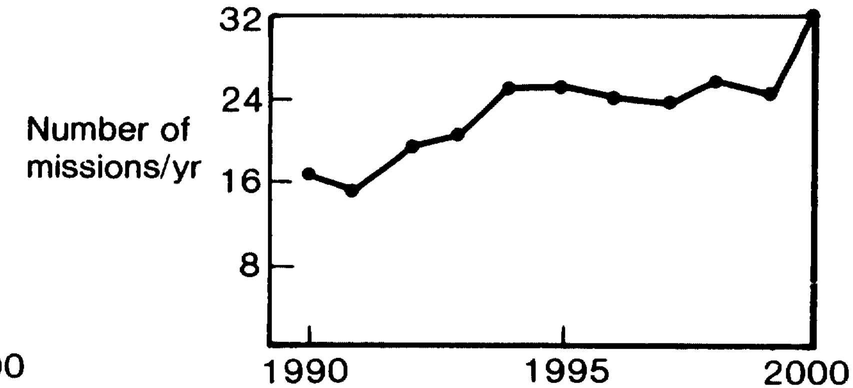
LEO/HEO
Emplacement/servicing/retrieval
High inclination



LEO/HEO
Emplacement/servicing/retrieval
Mid-inclination



GEO emplacement



Conclusion: Approximately 75% of free-flyer missions can be serviced from a 28.5-deg orbit station

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A number of conclusions can be drawn from the mission requirements analysis. The mission requirements derived during this study provide a rational basis for architectural option evaluations. They are sufficiently representative of activities that can be expected for the 1990's to permit the definition of an appropriate manned Space Station system.

A manned Space Station will provide major performance and economic benefits to a wide range of missions planned for the 1990's. Most of the manned research, development and production missions require, prefer or will accept a 28.5°, 400-500 km orbit.

There are 11 man-operated missions that prefer a polar orbit of which 4 will accept a range down to 28.5°. These occur throughout the decade. Fortunately those that occur in the earlier years will also accept alternative accommodation as a free flyer.

Of the 16 man-operated missions that prefer mid (~ 57°) inclination orbits, 8 will accept a range down to 28.5° and the balance require 57° or higher inclinations. Some of these are also suitable for accommodation as free flyers although they prefer manned.

The role that man performs for these missions varies from vital to a beneficial contribution. As expected, a high percentage (70%) of the missions assigned to the Space Station have a vital role for man and only 11% fall at the low end of the scale. These usually will accept alternative accommodation as free flyers.

Free flyers, which do not lend themselves readily to a manned Space Station because of their particular requirements, will be operational thorughout the decade. These occur at a variety of orbit altitudes and inclinations ranging from 28.5° to 100°, but many fit the expected Space Station orbit. Providing periodic service to these free flyers will improve their performance output, enhance their cost effectiveness and probably reduce total cost as well. A number of the free-flyer missions are candidates for accommodation on an unmanned platform. The balance would be independent satellites.

Although preliminary studies indicate a need for separate Station(s) for operational DoD missions, combined NASA and DoD RDT&E missions are feasible and desirable on a LEO, 28.5° Station.

ANALYSIS OF MISSION DATA
Results

- Baseline mission set is representative & provides rational basis for architectural solution & required capabilities of station
- A large majority (85%) of the identified RD&P missions are suitable for a 28.5-deg, 400-500 km station
- 11 missions prefer a polar orbit
- 16 missions prefer mid-inclination orbits
- Man's role is vital to 69 missions, will significantly enhance 19 others & will contribute to the value of the remaining 11 missions in the mission set (Class 1)
- Free-flyer emplacement, servicing & retrieval required at low, mid & high inclinations throughout 1990s
- Identified DoD R&D mission requirements considered to be compatible with non-DoD missions

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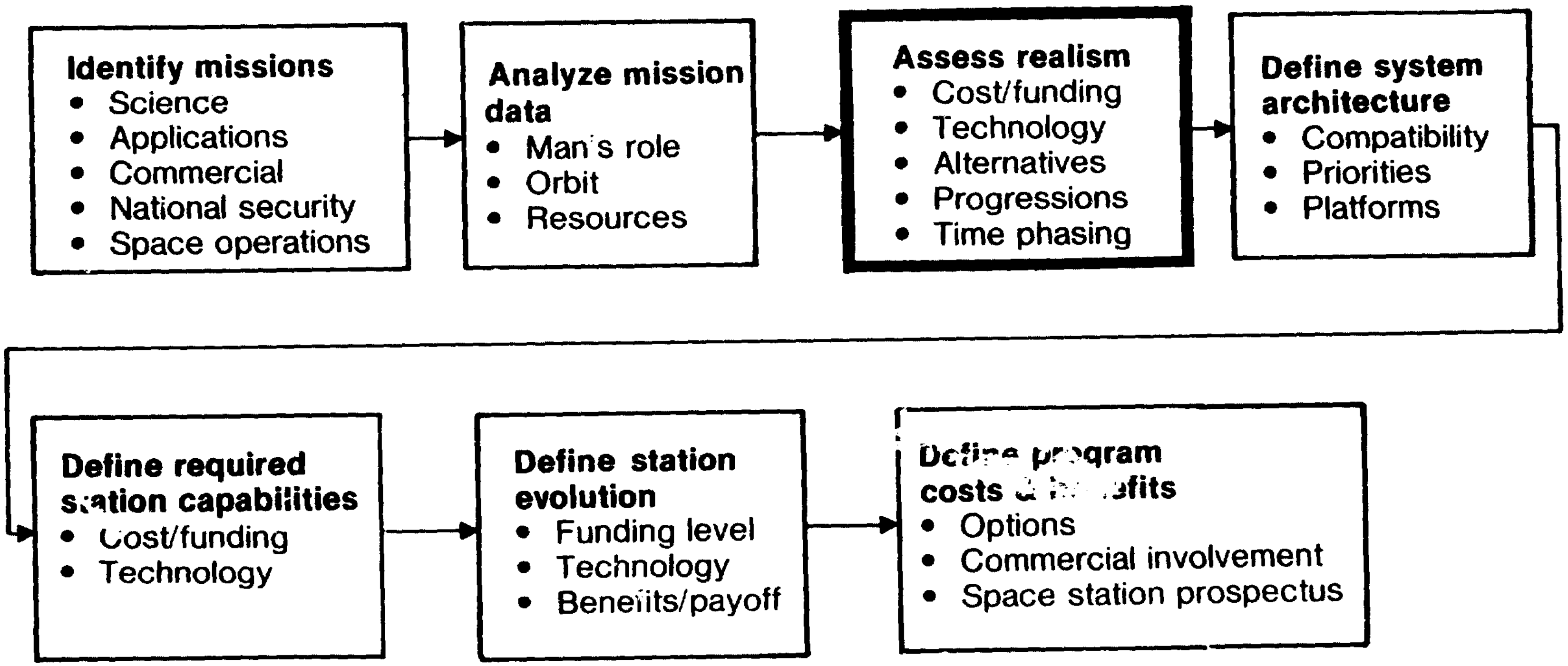
Evaluation criteria were identified to assess the realism and validity of our "total mission set." This analysis was carried out to assure definition of a defendable set of missions, and the eventual definition of a justifiable Space Station system architecture. This activity, and the major results, are presented in the next section of our briefing.

SPACE STATION STUDY LOGIC



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The work done throughout the study to identify uses and their requirements produced the mission set described earlier. This "Users Set" provides a menu of representative missions whose requirements have been validated to the degree that they can be used to establish a basis for architectural option studies. The missions are more concentrated in the early timeframe because people tend to concentrate more on near term than long term planning, however this did not create serious problems with the accommodations analyses. Some of these may also be optimistic in terms of technology readiness for this timeframe.

The study mid-term redirection called for the definition of "validated and realistic missions sets and associated requirements" as a study output. A set of criteria were established and a process defined for evaluating the user defined mission set to determine its realism. Other than planetary, no missions were excluded from the analysis or dropped from the set on a a-priori basis.

The planetary missions were excluded from the analysis because of their limited involvement with the Space Station program. They are part of the high energy staging traffic model but represent only 12 missions in the decade. Half of these are planned before the OTV is expected to come on line in 1994. If the set becomes reduced or schedules change, the impact on presently estimated OTV traffic will be minimal.

The analysis was not performed for commercial missions because it was felt that if the need was there, the funding would be also and so would the schedule demand. No technology barriers were identified and the only major accommodation resource delta was for materials processing power levels. These could be satisfied at reasonable cost.

DEFINITION OF A BASELINE TIME-PHASED MISSION SET

Evaluation criteria

- Is mission planned or approved by NASA?
- Are requirements traceable?
- Is mission cost commensurate with need & benefits?
- Does mission accommodation imply major station cost delta?
- Is mission definition sufficiently mature?
- Is required technology base available?
- Are alternate accommodations available?

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Using the criteria previously established, an analysis was conducted separately for the two subsets: man-operated missions and free-flyer missions. The recommendations were to be one of the following: delete, maintain time phasing with another mission, fly on schedule or permit rescheduling at the discretion of the accommodation analysis activity. The reschedule options were: fly on/near schedule, fly near to schedule and candidate for rescheduling; which meant, in general terms: 0-1, 1-2 and 2-4 years, respectively.

All the missions requirements were traceable and the only significant accommodations delta was for the commercial materials processing power requirements. As these were achievable at reasonable cost, this was not treated as unrealistic. However, they have been separately identified.

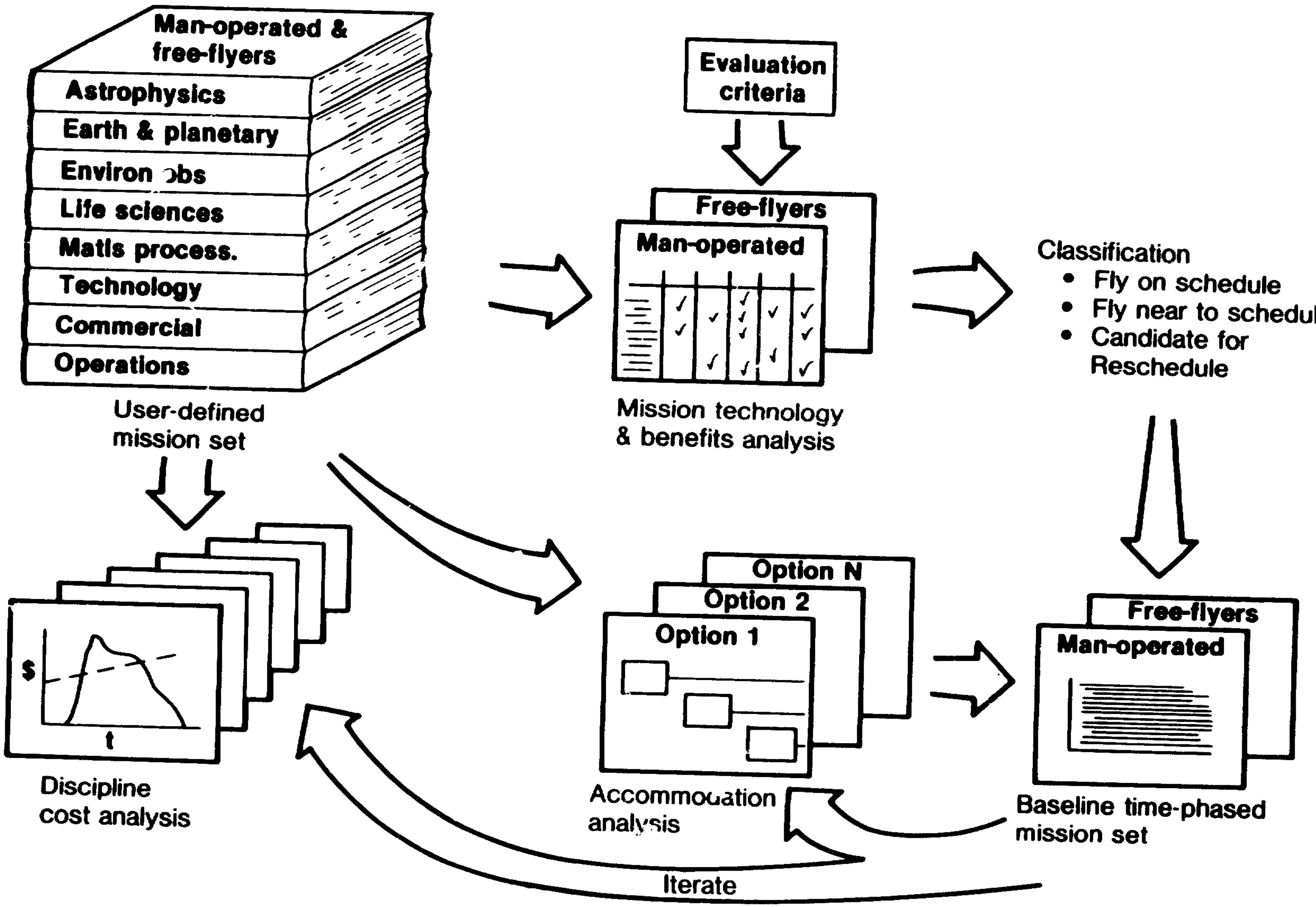
The results of the previous accommodation and architectural option analyses were taken into consideration also. Their principal contribution was to divert some man-operated missions to free flyers and to delay some polar inclination man-operated missions to a more suitable timeframe for a second Space Station.

Major evaluation factors were:

- Technology progression
    - Predecessor event/mission
    - Advancement as a major or moderate step
- Technical Risk
    - High
    - Medium
    - Low
    - Area of risk for medium and high categories
- Maturity of the mission definition

The results were documented on up-dated time phasing charts, missions requirements matrices and free flyer payload mission model summaries.

MISSION SET EVALUATION PROCESS



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Of the 99 missions recommended for man-operated accommodation based on user requirements, 16 prefer a 57°, or thereabouts, orbit. There are two types of alternative accommodation flexibilities provided. The first is to use a free flyer, which could be a platform. Of the sixteen, six are suitable as free flyers because of a lesser need for direct crew involvement.

The second flexibility is in acceptable orbit parameters. Eight missions will accept orbit inclinations as low as 28.5° and 13 will accept orbit inclinations up to 90°. There are, of course, intersections between these various subsets -- both for alternative inclinations and accommodation modes.

When all factors, including the acceptance schedule variation judgments that came from the technical risk/technology evaluation are considered, the selected accommodations are as shown.

The conclusion is that these missions were not sufficient to require either a separate station or the prime "low" inclinatin station to be at 57 degrees.

ALTERNATE ACCOMMODATIONS

57-deg orbit

- Sixteen missions prefer 57-deg orbit
  - Six missions are suitable as free-flyers
  - Eight missions can accept a 28.5-deg orbit
  - Two missions can accept a 90-deg orbit

Conclusion: Accommodate all remaining man-operated missions originally planned for 57-deg orbit at either 28.5-deg or 90-deg orbits

30033258-172

Of the 99 missions recommended for man-operated accommodation based on user requirements, 11 prefer orbits at or near 90°, i.e., polar. Two of these will accept accommodation as free flyers. Four will accept orbits as low as 28.5°. One will accept an orbit inclination as low as 57°, but that is of little interest because the need for a station at that inclination has already been discounted. Because of their early schedule requirement versus a late decade availability of a second station in polar orbit, the two missions that could accept free flyer accommodation were moved to that mission class. The four that would accept low inclinations also had early schedule dates and were accommodated on the 28.5° station.

The balance of five missions plus the two reassigned from the 57° orbit made a total of seven man-operated missions in the later years assignable to the second, polar Space Station. These were all Earth exploration or environmental observation types for whom man's role was vital or had a high significance.

The free flyer operations and servicing traffic for a polar inclination Space Station is fairly light. This includes DoD emplacement traffic suitable for an OTV.

The conclusion is that although there are requirements for a second station in polar orbit in the 1997-2000 time period, they are limited. Delay of a station to meet these requirements will increase the cost of free flyer servicing and cause a significant data reduction or loss from user defined man-operated missions.

ALTERNATE ACCOMMODATIONS (continued)

90-deg orbit:

- Eleven missions prefer polar orbit
  - Two missions are suitable as free-flyers
  - Four missions can accept a 28.5-deg orbit
- Summary of remaining polar orbit missions (1998-2000)

Type Facility	No. Missions	Description	Evaluation
RD&P	7*	• Earth exploration • Environmental observations	• Not compatible with 28.5-deg station • Manned interaction vital • Significant data/resource loss until 90-deg station provided
Operations & servicing	6 4	TMS missions/year OTV missions/year (DoD)	• If 90-deg station unavailable, shuttle launched & serviced missions more costly & mass limited

*Including 2 missions originally planned for 57-deg orbit

Conclusion: Limited mission requirements exist for a 90-deg station late in the next decade

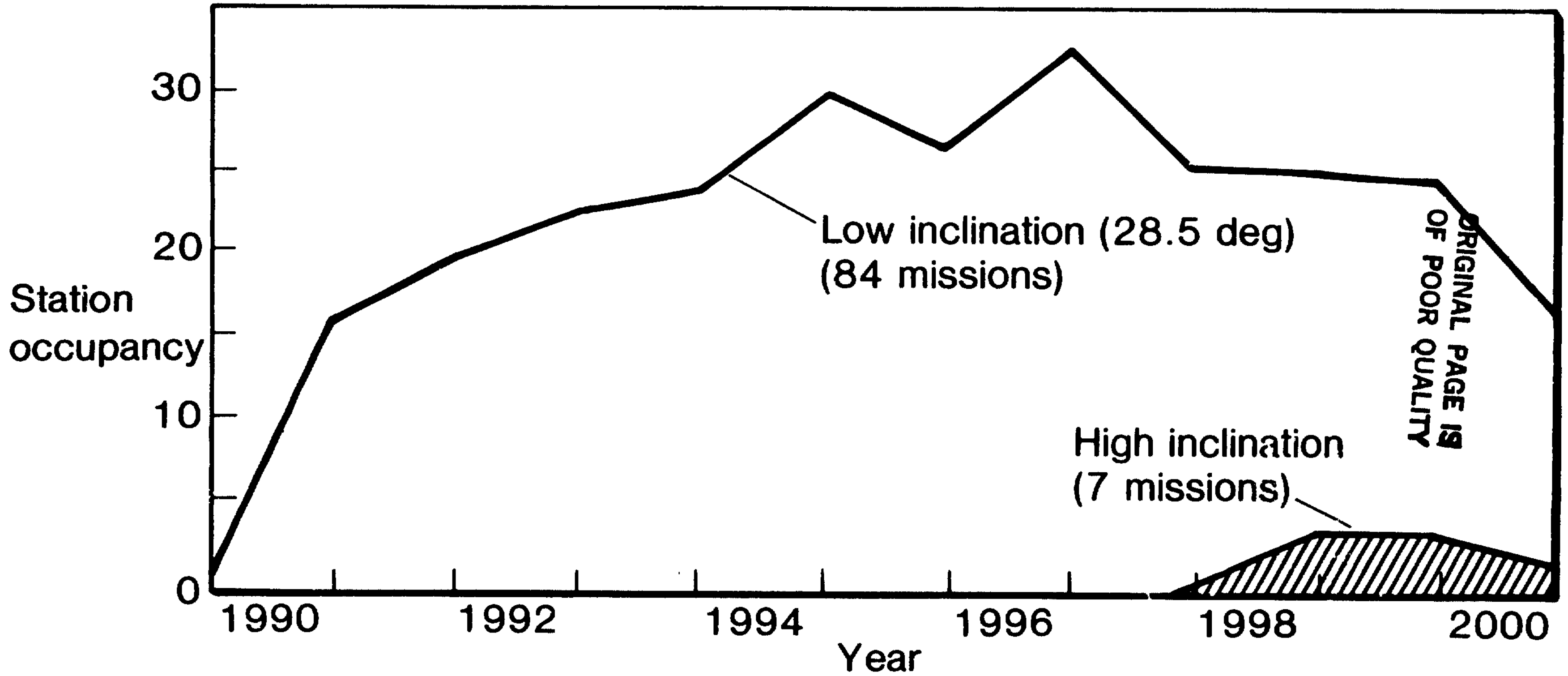
The distribution of man-operated missions over the decade is improved from that based strictly on near defined requirements. There is some scatter in the mid years and still some drop-off in the later years indicating a continued presence of the planning horizon effect.

Two separate curves representing the number of payload elements present at years end are provided. The lower, shaded, curve is for missions that would be accommodated on a polar Space Station, assuming it went into operation in 1998.

The upper curve is for those missions on the 28.5° Space Station. This Station accommodates approximately 92% of the man-operated missions. Occupancy for Station-attached payload elements is shown to peak at a level of 31 and maintain a level of about 30 for a 5-6 year period. During this time, some of the shorter duration missions come and go while others are added.

Twelve percent of the missions have Shuttle-compatible mission durations; which could be candidates for continued Shuttle support, although in themselves they do not constitute complete Spacelab missions. They are carried in the Space Station era as representative of typical quick turn-around missions which could be decoupled from time-constrained Shuttle transportation operations.

BASELINE TIME-PHASED MISSION SET
Man-Operated Missions

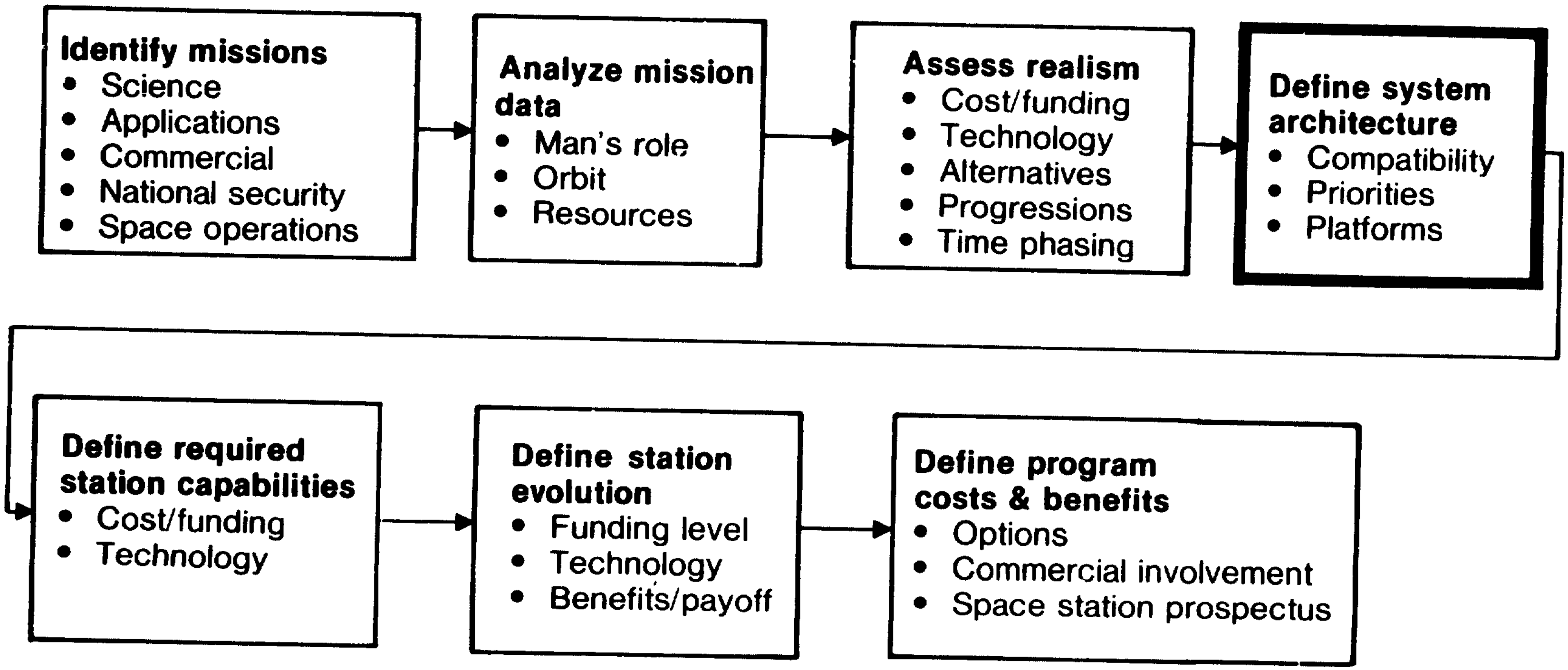


Conclusion: 28.5-deg station captures approximately 92% of man-operated missions

30033258-148

The next step in our study process was to define an overall Space Station system architecture which is consistent with the requirements of our "baseline mission set." This architecture and the rationale which lead to its definition is outlined in the next section of our briefing.

SPACE STATION STUDY LOGIC

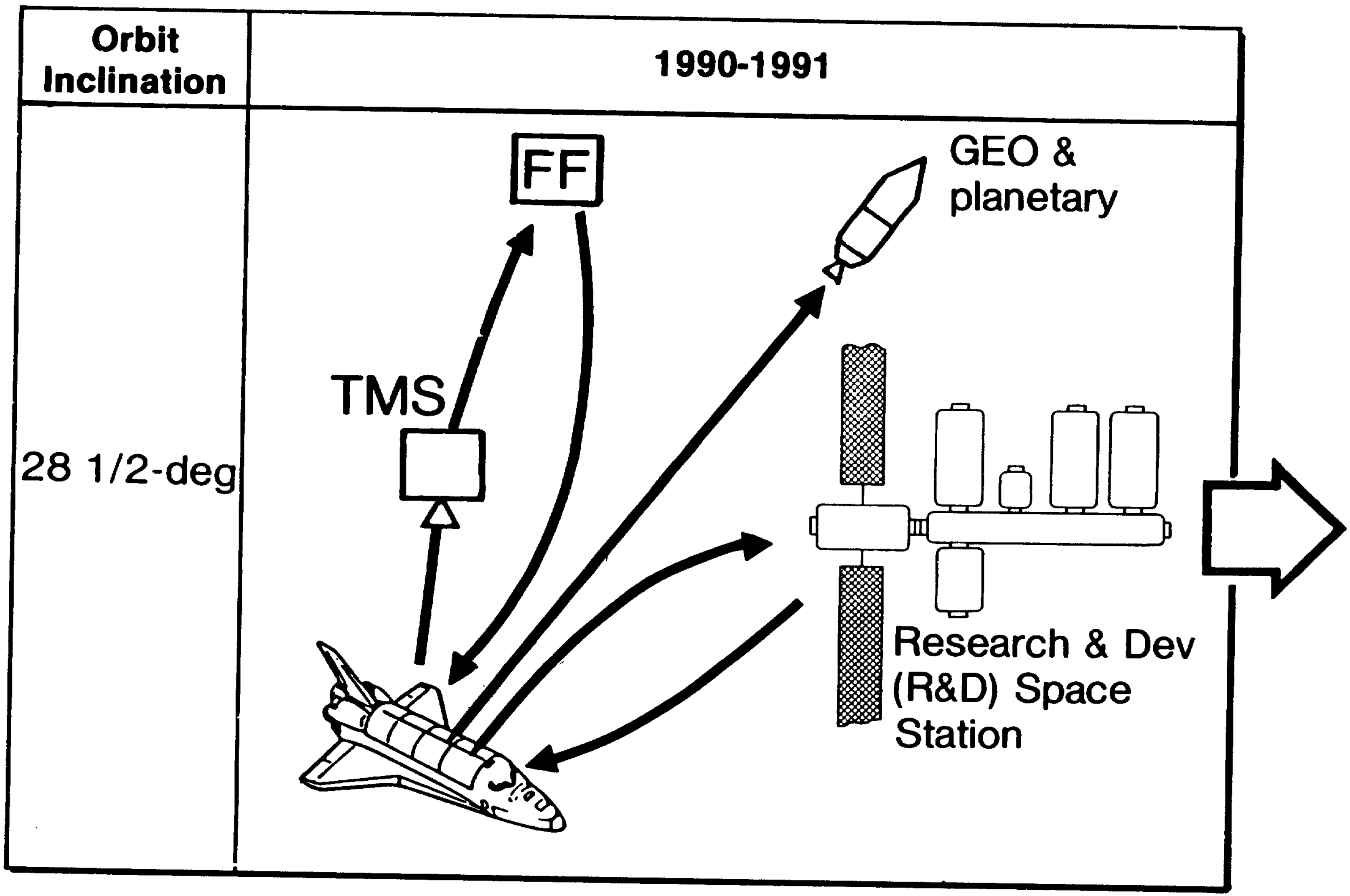


30033258-160

The following two charts show the evolution of the proposed space system architecture in the 28.5° orbit over the next decade.

The chart on the facing page illustrates that during the first two years of the decade the initial research, development and production facility is brought into service (IOC 1990). During this time period, launch of GEO and planetary spacecraft would be performed by OTV's from the shuttle (or expendable launches). LEO spacecraft servicing would be performed by a TMS from the shuttle.

SPACE SYSTEM ARCHITECTURE



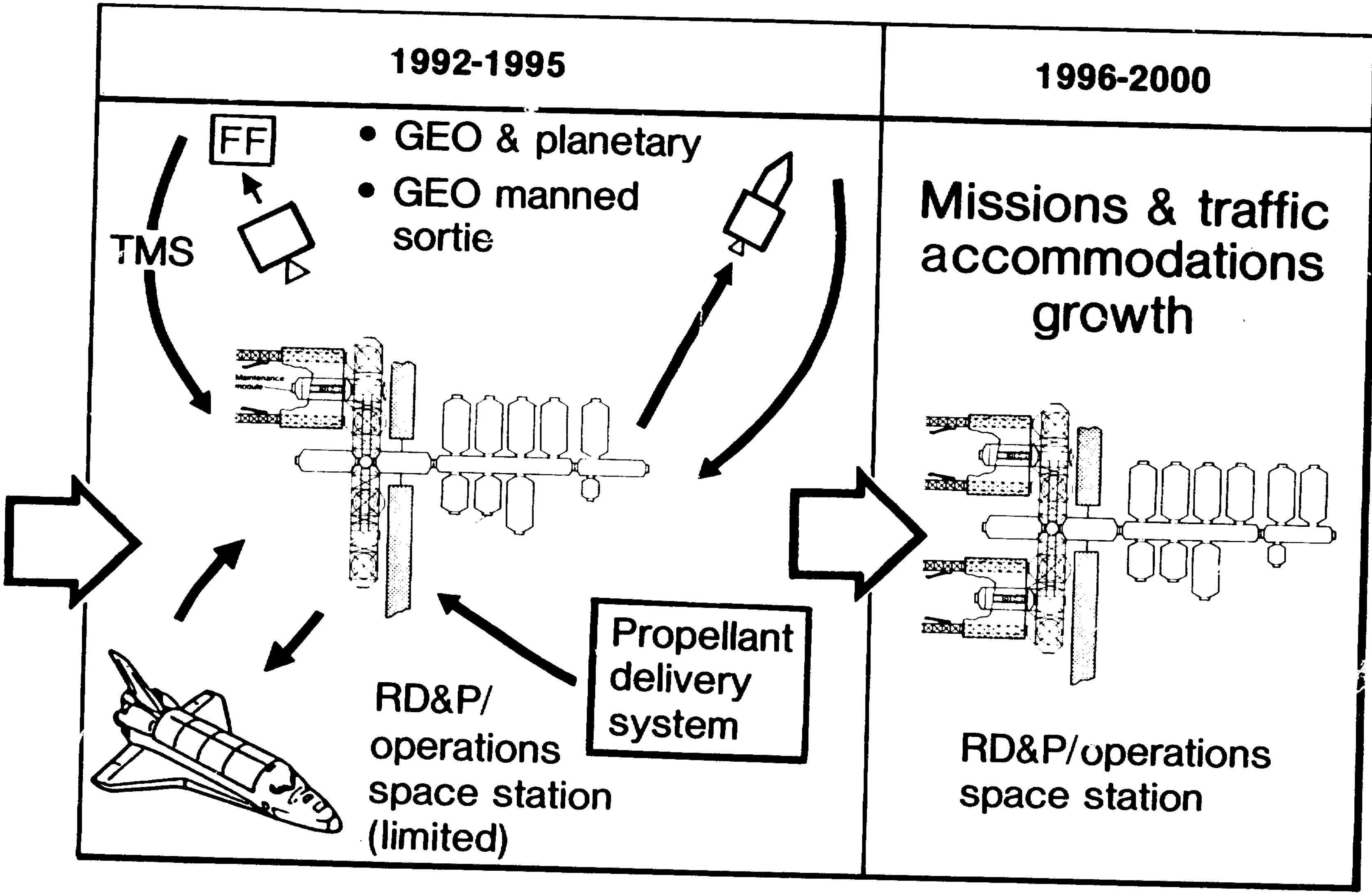
30033258-130

During the time period from 1992 to 1995, the initial research development and production facility will be augmented with a servicing and operations capability. For this purpose, a TMS base will be developed on the station for servicing of LEO free flyers. Provisions for maintenance, repair and operation of a space based OTV will also be attached to the station during this time period. Considering the amount of propellant required to support OTV activities during this period, a system (ET tanker) for delivery of large amounts of propellant to the station will also be required. Development of a system to maximize the amount of propellant which can be extracted from the shuttle external tank should also be developed. This approach will significantly enhance the economic benefits of the space based OTV and reduce the amount of propellant to be carried to the station by an ET tanker.

Full operational capability of the space based OTV on the Space Station will be available by 1994. Performance of all final technology development activities as required to support this operational capability will have been carried out on the station during the previous three years. The proposed approach is to develop this OTV launch capability as rapidly as possible since this activity provides the most significant economic justification for a Space Station.

In 1996, a second OTV maintenance, repair, and operational facility will be added to the station. This will provide the launch capability required to satisfy the free flyer traffic model. In this configuration the shuttle need only deliver satellites to the station, and would not be required to stay on orbit for extended periods to support satellite launch activities. This will significantly enchance the operating efficiency of the shuttle.

MISSIONS SET SUPPORT SPACE SYSTEM ARCHITECTURE

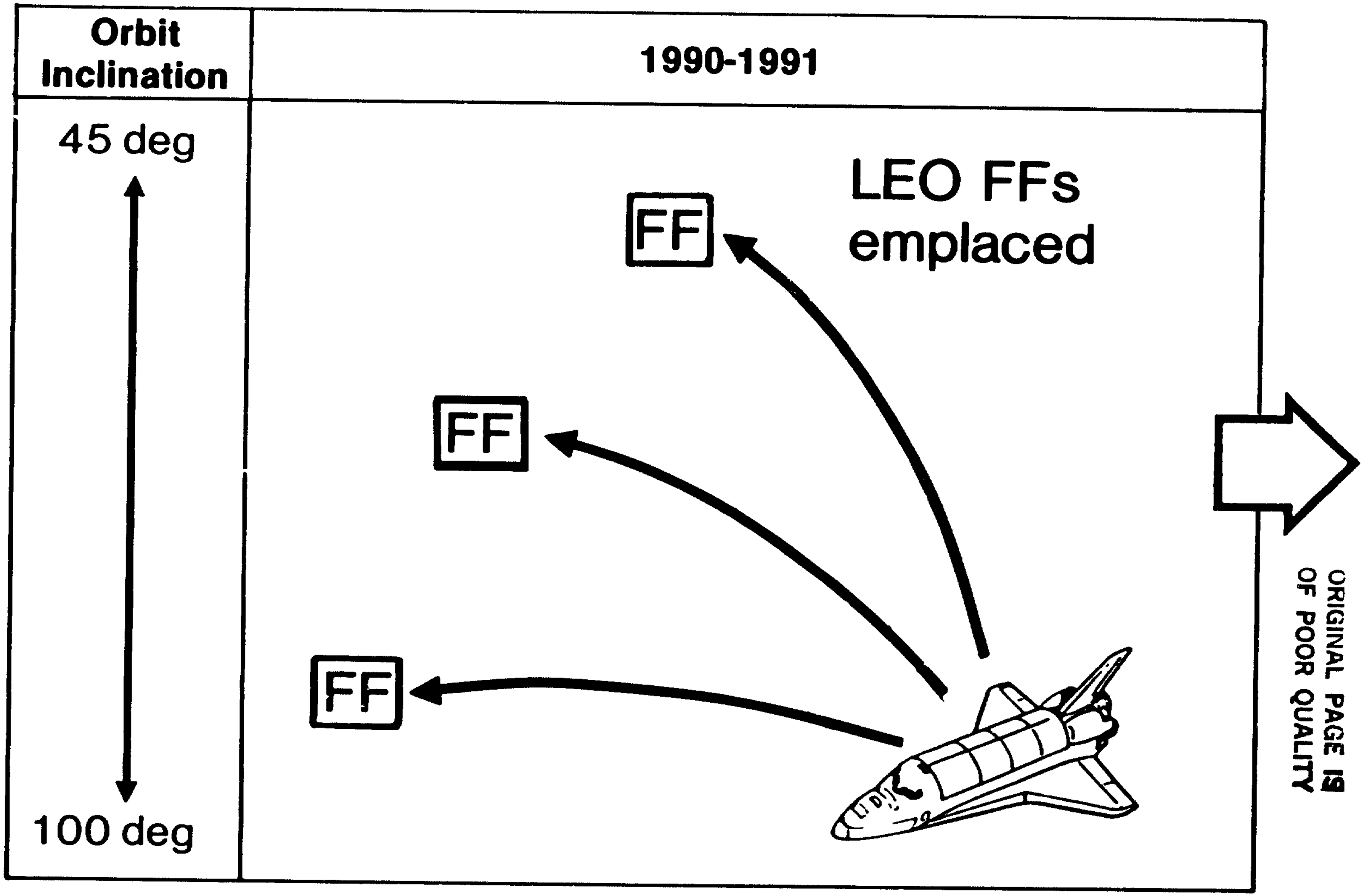


30033258-131

The following two charts show the evolution of the proposed space system architecture in the higher inclination orbits.

During the initial two years of the decade, emplacement of free-flyers in LEO will be from the shuttle utilizing existing systems (or with expendable launchers).

SPACE SYSTEM ARCHITECTURE



30033258-132

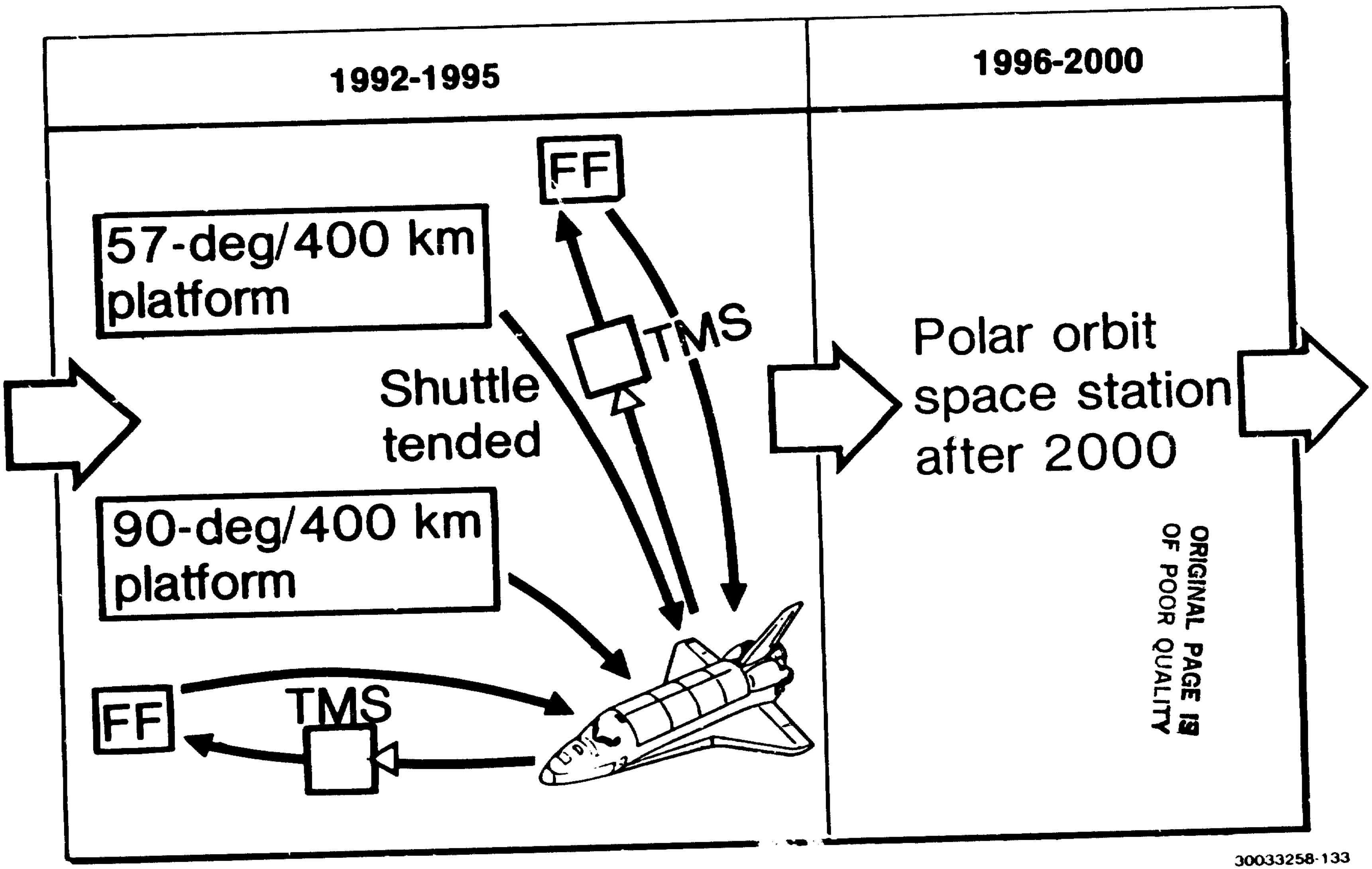
During the time period from 1992 to 1995, two platforms are installed, one in a 57° orbit and the second in polar orbit. These platforms consist of specific mission payloads defined later.

Initiation of satellite servicing operations from the shuttle, using a TMS, will also occur during this time period. Servicing of the platforms by TMS will be included. The capability to service several payloads on the platform in one servicing operation is an additional benefit which is derived from the platform approach.

Finally, as regards the polar orbit station, we foresee its implementation shortly after the year 2000 based on a projection of mission requirements as developed to date. The rationale which lead us to this conclusion is discussed on a subsequent chart.

GENERAL DYNAMICS
Convair Division

SPACE SYSTEM ARCHITECTURE



30033258-133

One major question which was addressed during the system architecture portion of our study dealt with the subject of joint vs. separate stations for research and space operations activities. At first glance, aspects related to OTV operation appeared incompatible, in several ways, with foreseen research activities (dynamic disturbances, contamination, safety, etc.). However, as a consequence of our study, we have concluded that joint research and space operations activities can be carried out on one station even though limited amounts of interference will obviously occur. In the final result, however, the delta cost for two separate stations is not considered justified. Timelining of certain activities to avoid, e.g., disturbances caused during OTV launch periods, will be necessary. Special precautions to avoid contamination of delicate instruments will also be required. Safety remains an issue of concern, however the same fundamental problem exists whether joint or separate stations are utilized.

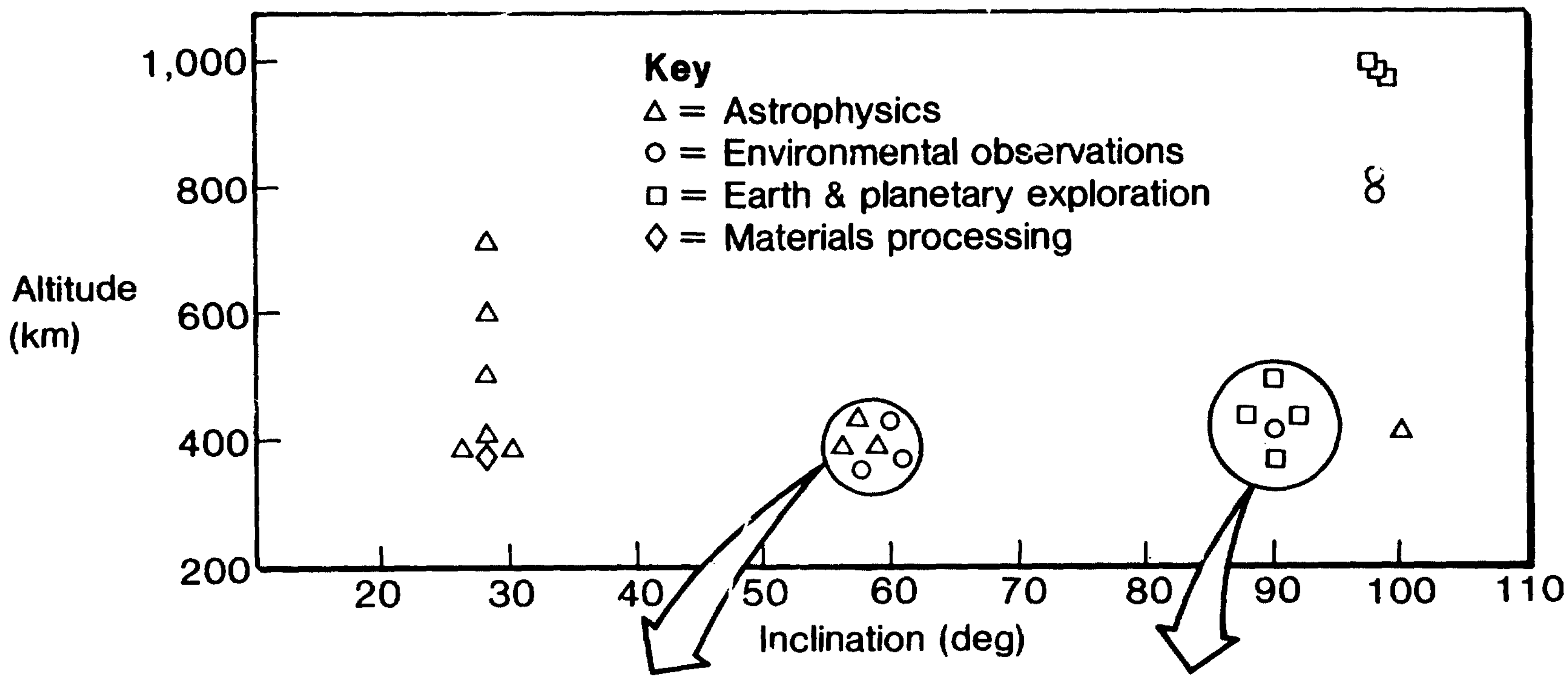
COMPATIBILITY OF JOINT RESEARCH & OPERATIONS ACTIVITIES ON A SINGLE STATION
Combined Facilities Concerns

Issue	Evaluation
• Environmental conflicts — Dynamic disturbances — Contamination	• Infrequent shutdown of sensitive missions required
• Scheduling conflicts	• Minimized by infrequent operations & servicing missions
• Cost of lost mission hours	• Approximately $200M over decade
• Growth limitations	• Growth through 2000 manageable
• Safety	• Significant concern but not a decisive factor

Conclusion: Joint research & operations activities can be carried out on the same station at least through the next decade

As a part of the overall system architecture, we propose the development of two LEO platforms, one in a 57° inclined orbit, and the second in polar orbit. These two platforms would contain six and five mission payloads, respectively, as shown on the facing page. Use of these platforms, will among other advantages, provide the opportunity for efficient servicing of the mission payloads.

LEO PLATFORMS



57-deg/400 km platform missions
Solar terrestrial observation
Upper atmosphere research
VLBI
Adv solar observation
Meteorology instruments
High-energy isotope

90-deg/400 km platform missions
Operational land system
Geoscience-geology
Firex
Ocean instruments P/L
Renewable resources

30033258-151

Our proposed approach to development of the polar Space Station is shown on the facing page. In summary, it is our conclusion that, based on the limited set of polar orbit mission requirements contained in our "baseline mission set," a strong justification for development of this station does not presently exist. Consequently, we propose that initiation of the development of this station be delayed until requirements become more firm and extensive, and until full benefit and experience is gained from the 28.5° station.

This conclusion can of course be appropriately modified should requirements mature faster than anticipated, in particular in the DoD area.

APPROACH TO DEVELOPMENT OF 90-DEG STATION

Limited requirements do exist for a polar station late in the next decade (8% of total missions)

- Marginal justification
- Mission planning not yet fully mature
- Definition of required station capabilities is difficult

The following programmatic approach is consequently recommended

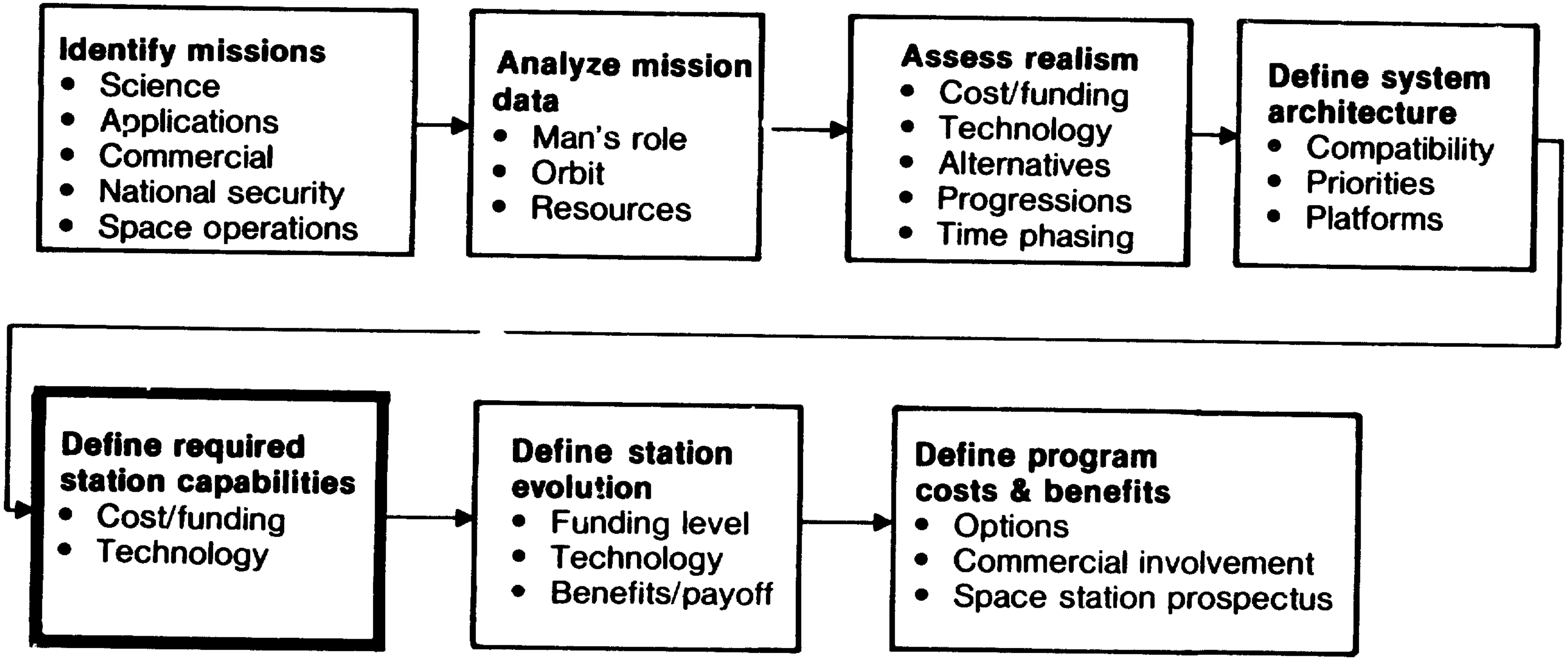
- Concentrate on definition & evolution of the full capability 28.5-deg station
- Allow polar orbit mission requirements to mature (including DoD requirements)
- Fully develop utility of 28.5-deg station prior to initiation of polar orbit station development

Conclusion: Polar orbit station IOC after end of next decade appears appropriate

30033258-175

Following definition of the system architecture, the required capabilities of the 28.5° station were defined in some detail. These included requirements such as crew size and time, power, data processing, pressurized volume, servicing and operations capability, etc. Typical results of this activity are discussed in the next section.

SPACE STATION STUDY LOGIC



30033258-161

As a first step in defining the required capabilities of the Space Station, the major Space Station attributes were defined as shown on the facing page. The station must accommodate the total baseline mission set and must provide the necessary resources to support these experiments. In addition the capability to emplace, service, and retrieve free flyers must be provided. The functions the Space Station must provide to support this capability are also defined on the facing page.

REQUIRED SPACE STATION ATTRIBUTES

Accommodates man-operated missions
- Micro-gravity
  - Life sciences
  - Materials processing
  - Technology development
- Outward looking
  - Astrophysics
- Earth pointing
  - Earth exploration
  - Environmental observation

Supports free-flyer missions
- LEO/HEO satellites/platforms
  - Emplacement
  - Service
  - Retrieval
- GEO satellites/platforms
  - Emplacement
  - Service
- Planetary satellites
  - Boost

Provides resources
- Crew time
- Power
- Data processing
- Command & control
- Thermal control
- Stable platform
- Pressurized volume
- Exterior mounting

Provides functions
- Assembly & construction
- Checkout
- Service
- Reconfiguration
- Maintenance & repair
- Transportation
- Storage

30033258-147

The crew size requirements were determined from our functional allocations analysis of OTV, TMS and Free Flyer servicing operations, analysis of the missions requirements for research, development and production missions projected station operation, and allowance for National Security Research and Development. The crew size is projected to be 5 by the end of 1990, rising to 12 by 1996. These numbers are based on an 8 hour work day with an additional hour allocated for housekeeping tasks. The crew size is divided in terms of equivalent man years allocated to each of the major areas of activity.

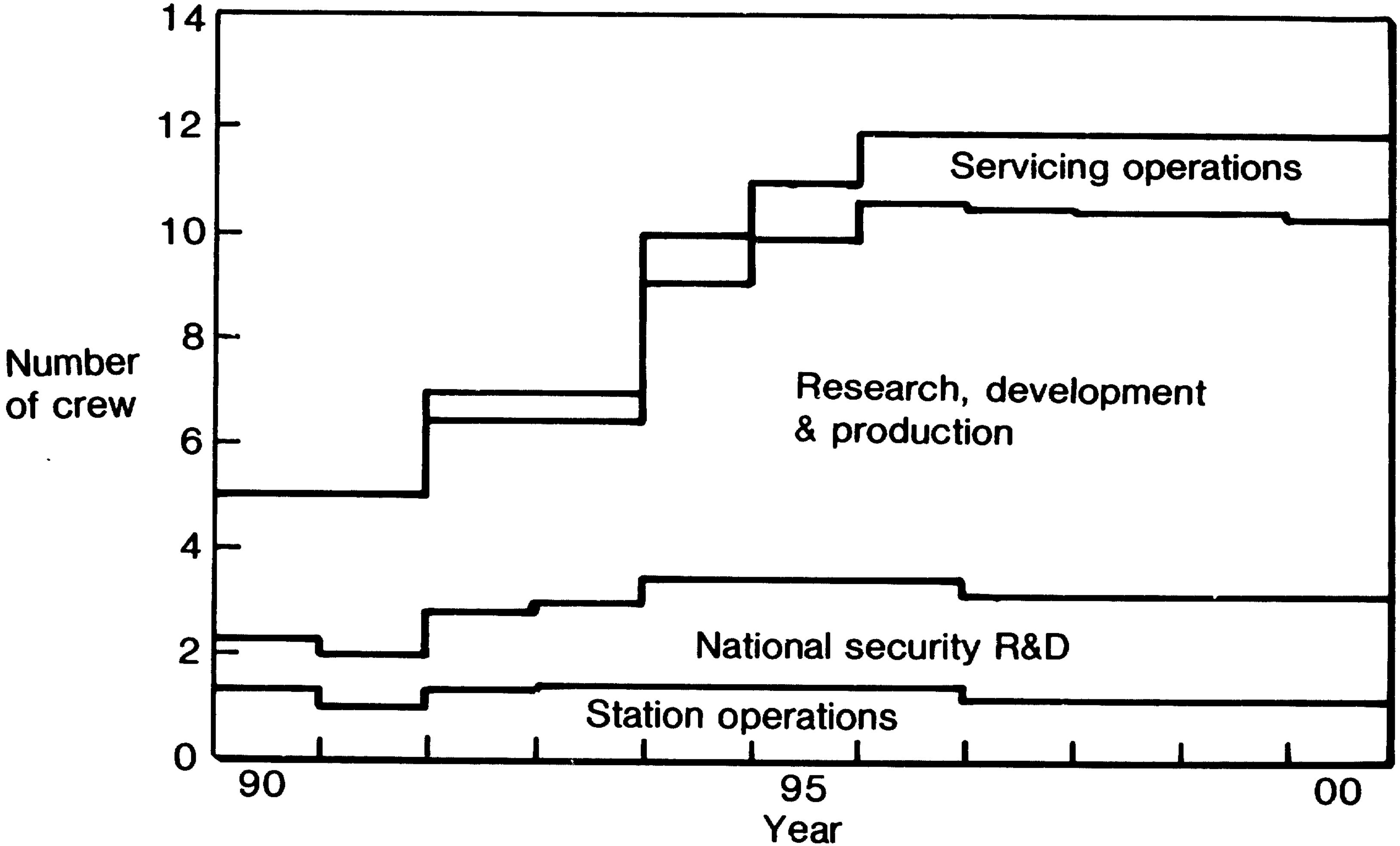
In determining the human role in the Space Station operations, the goal is to find a combination of human and machine tasks that would utilize the human capabilities for the greatest economy in carrying out planned missions.

The human role is based on his or her unique ability to

a) respond to unforeseen emergencies
b) perform contingency activities
c) perform self contained operations in absence of ground communication
d) carry out investigations
e) repair and improve equipment.

Machines are best used to perform hazardous operations, repetitious activities, and extend the capabilities of humans.

28.5-DEG SPACE STATION RESOURCE REQUIREMENTS
Crew Size



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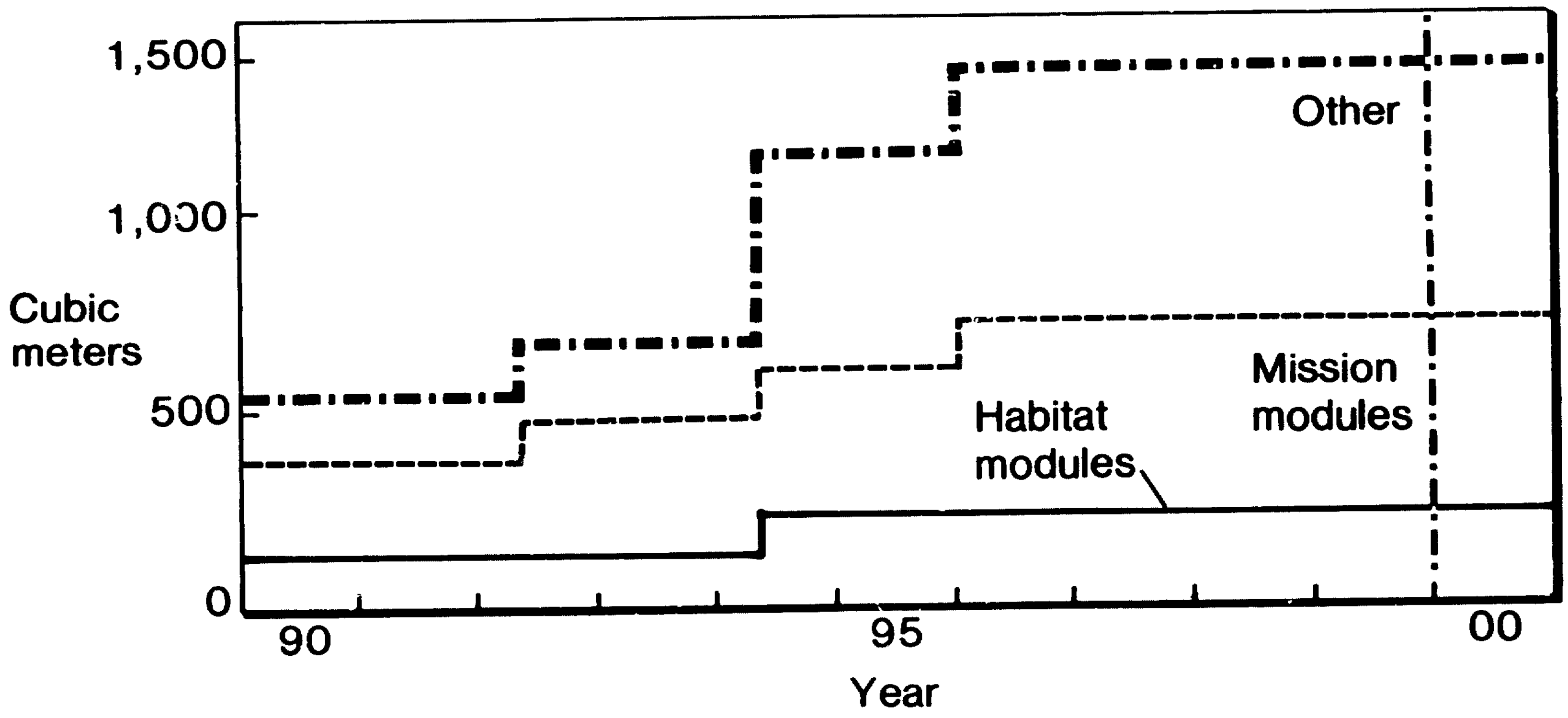
30033258-181

The habitable volume of the Space Station is defined as that pressurized volume available for equipment, storage, or crew accommodation. Due to the shape of the modules (round) and the pressurized volume requirement for subsystems, the habitable volume is typically about 70% of the total pressurized volume available.

The habitable volume shown opposite is composed of Habitat Modules, Mission Modules, Maintenance Modules, Accessways, and the Operations/Utility Module. The Logistics Modules are not included, as they are intended solely as temporary modules.

The major increase shown in 1994 reflects the addition of the OTV Mission Module, first Maintenance Module, and the second and third accessways.

28.5-DEG SPACE STATION MISSIONS ACCOMMODATIONS CAPABILITIES
Habitable Volume



3033258-186

The Space Station user requirements for power were complied from the baseline mission set for the 28.5° Station. The graph shows the total time-phased maximum power required to accommodate missions and power the Station through the year 2000. Although an effort was made to minimize the total power profile, there was insufficient data available to schedule power needs. The requirement reflects our best effort to compress power needs based on the information available.

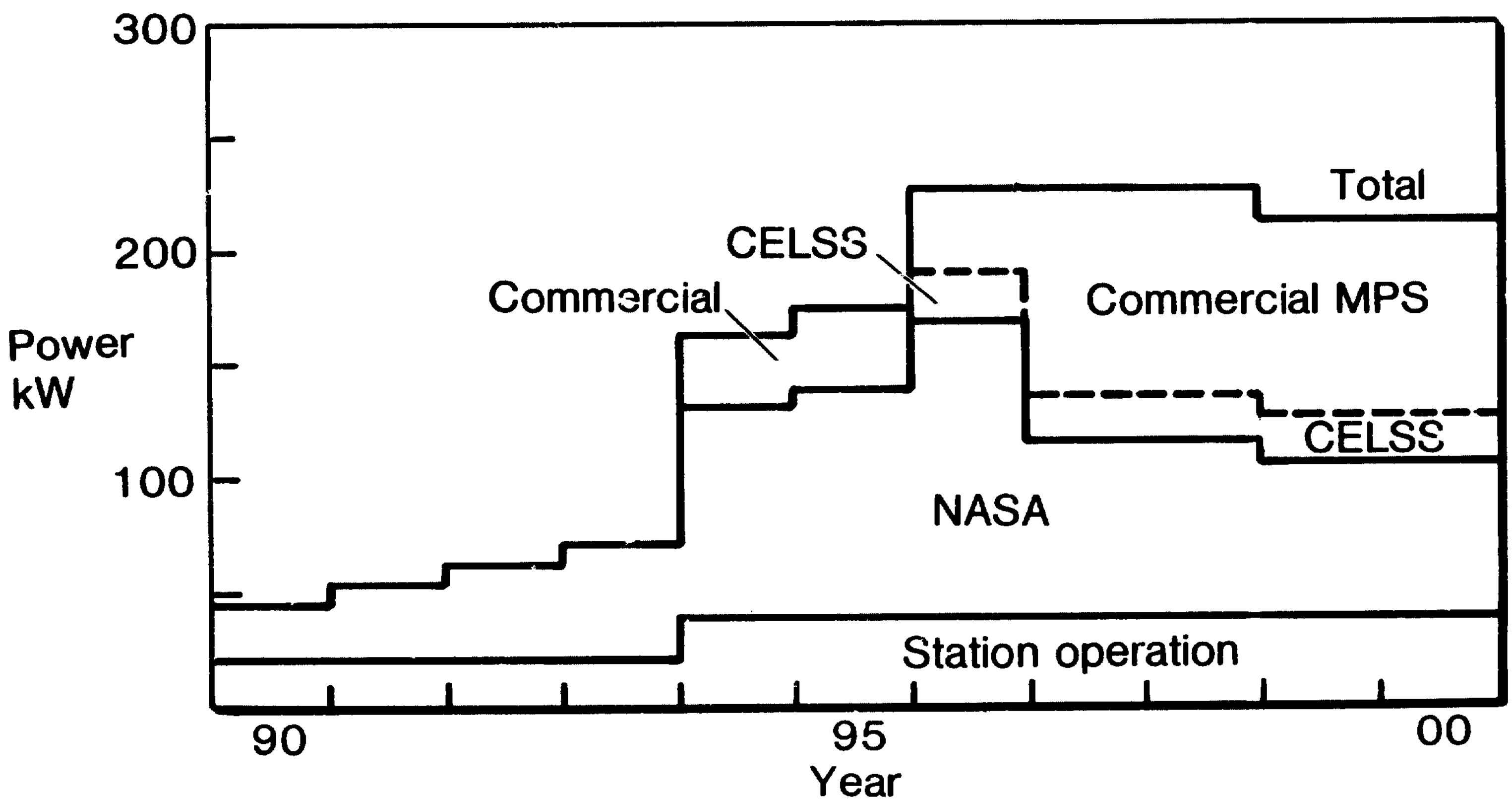
The increase in power requirements later in the decade occurs for two reasons:

a) The expectation that Materials Processes Science (MPS) will mature, and a significant user need for the added power will result.

b) The expectation that toward the end of the decade, closed loop life support systems (CELSS) will be used to support the Station to mimimize the cost of resupplying crew consumables.

Should these events fail to occur, the requirements will be reduced. On the other hand, should MPS users needs develop more rapidly, even more power would be required.

28.5-DEG SPACE STATION RESOURCE REQUIREMENTS
Power Requirements



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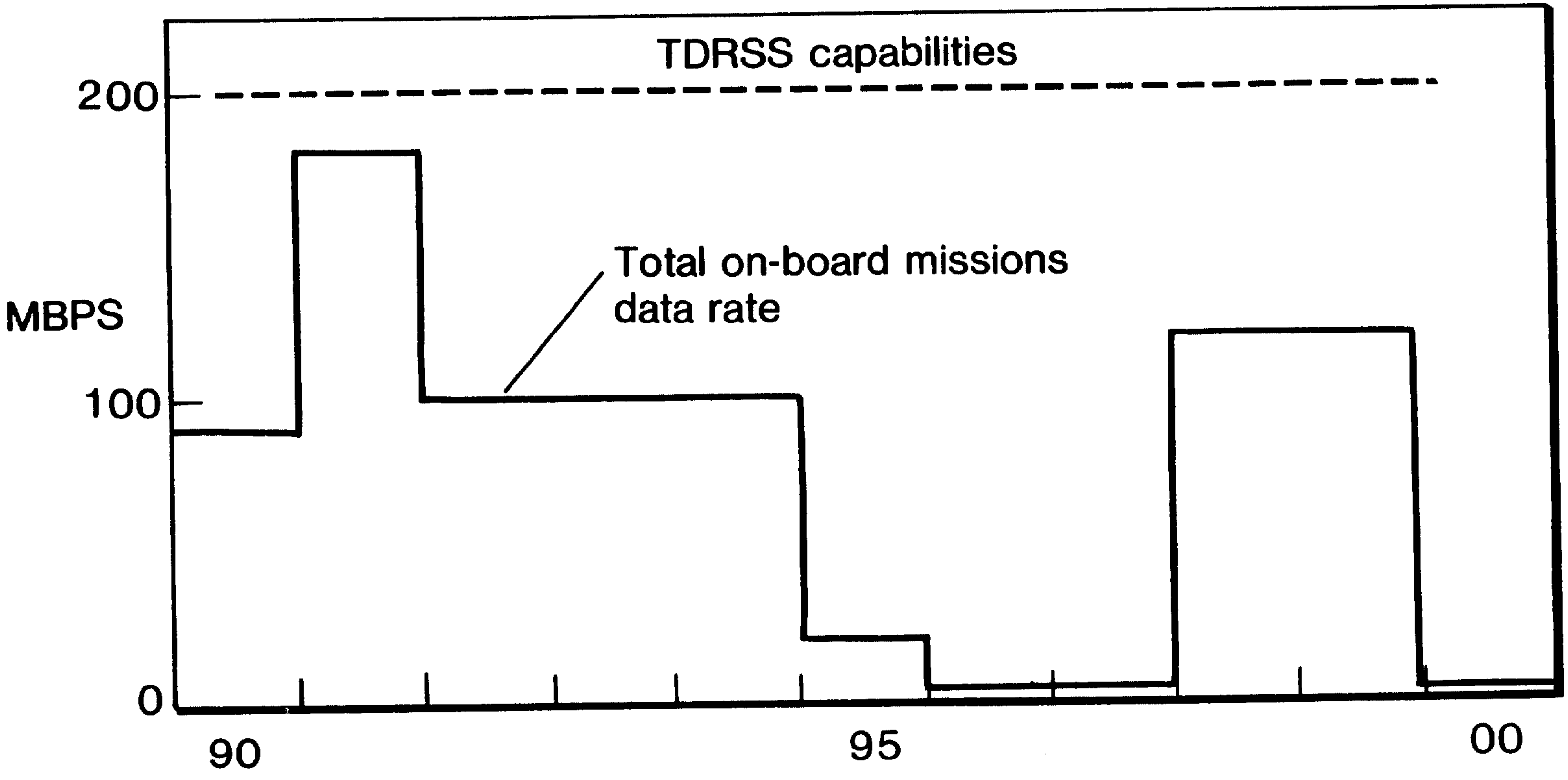
30033258-180

The TDRSS will be the prime method of relaying experiment data to the ground prior to 1995. TDAS, having benefits in both available data capacity and enhanced ground distribution of data, will be used post-1995. The TDRSS has a 300 MBS limit for one K-band single access (KSA) channel. Fifty MBS of data, which includes 2 slow scan video links, have been allocated to basic space platform. The TDRSS has a zone-of-exclusion over the Indian Ocean that requires recording of data when the Space Station passes over this zone and later transmission of this data. Fifty MBS has been allocated for this playback leaving 200 MBS of data available for experiments when a single KSA channel is used.

The total mission set was reviewed for data rate requirements (149 missions). As shown on the facing chart, total data requirements for missions attached to the 28.5° Space Station are TDRSS compatible. Only 6 free flyers in the Earth and Planetary Exploration category have rates in excess of 200 MBS. Therefore, 143 of the 149 experiments can be flow in the TDRSS era using one KSA channel. The 6 high rate experiments (each is 300 MBS) could be accommodated using bo-th TDRSS KSA channels, using video compression on the data, recording the data and playing it back at a slower rate, by analog transmission of the data through a COMSAT or by bulk transportation of the recorded data to earth using an Orbiter as the carrier. Since two of the six will be flown in the TDRSS era, this technique will be required to accommodate them.

The TDAS will feature high data rate laser links and accommodating data rates up to the gigabit-region will be possible.

28.5-DEG SPACE STATION MISSIONS ACCOMMODATIONS CAPABILITIES
Data Transmission



96% of missions set is TDRSS-compatible

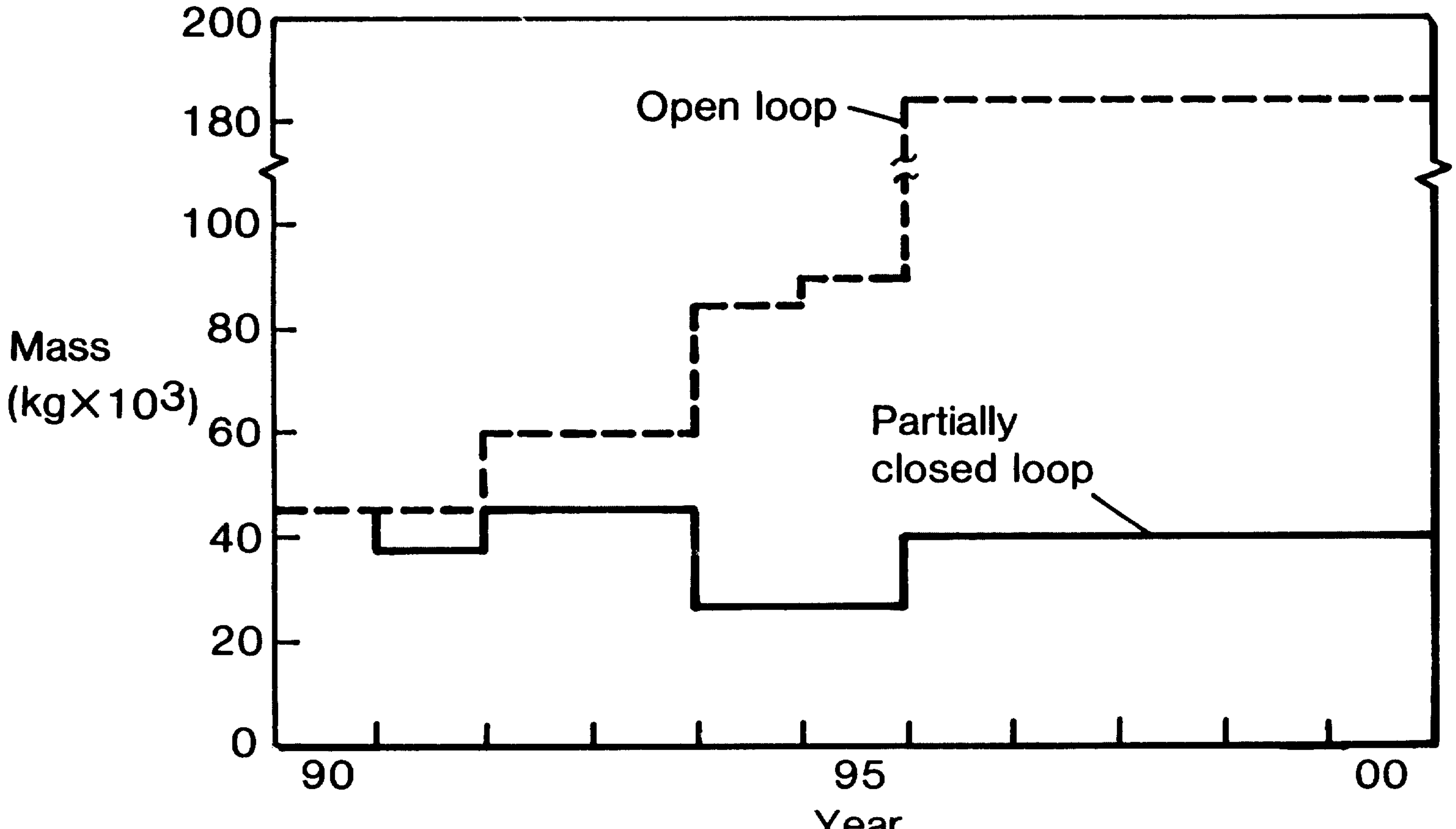
30033258-184

The crew consumables consist of water, food, atmosphere, personal supplies, spares and EVA supplies. The graph shows the mass by year for a completely open environmental control/life support system (EC/LSS) and the reduction in mass when a partially closed system for water, food and atmosphere are implemented.

The recommended stragegy for closing the EC/LSS is as follows:

1. Launch Open Loop System initially (5-MAN) using Shuttle technology. As experiments, install a 2-man water recovery system for cabin humidity condensate recovery via multi-filtration and wash water and a urine recovery via thermoelectric integrated membrane evaporation system.
2. Partially (33-40%) close the water loop within first year. Provide 90% closure within first 3 years (entire crew).
3. Install a 2-man CO_2 removal system (as experiment) within the first 2 years using solid amine-steam desorbed process. Provide an operational CO_2 removal system, (100% excluding EVA) within the first 4 years (entire crew).
4. Install a 2-man O_2 generation system (as experiment) within first 3 years, using solid polymer electrolysis process. Provide an operational O_2 generation system within the first 5 years (entire crew).
5. Provide a N_2 generation experiment, 2-man system using catalytic dissociation of hydrazine, within 4 years. Provide operational system within first 6 years.
6. Install a CO_2 reduction experiment, 2-man system using Sabatier process, within 4 years. Provide an operational system within 6 years.
7. Grow food (as experiment) e.g., lettuce, tomatoes, wheat, peanuts, soybeans, during first five years; operational food production for 50% of crew needs within 6-7 years. (Assumes crew of 8).
8. Install a 2-man solid waste recycling system experiment using wet oxidation process within first 4 years. Provide an operational system within 6-7 years.

28.5-DEG SPACE STATION RESOURCE REQUIREMENTS
EC/LSS Consumables



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This chart depicts propellant requirements per year to support the baseline OTV mission model. The figure therefore represents a ma·imum propellant requirment. Given a nominal 60-80% payload capture ratio the propellant requirements will be reduced correspondingly.

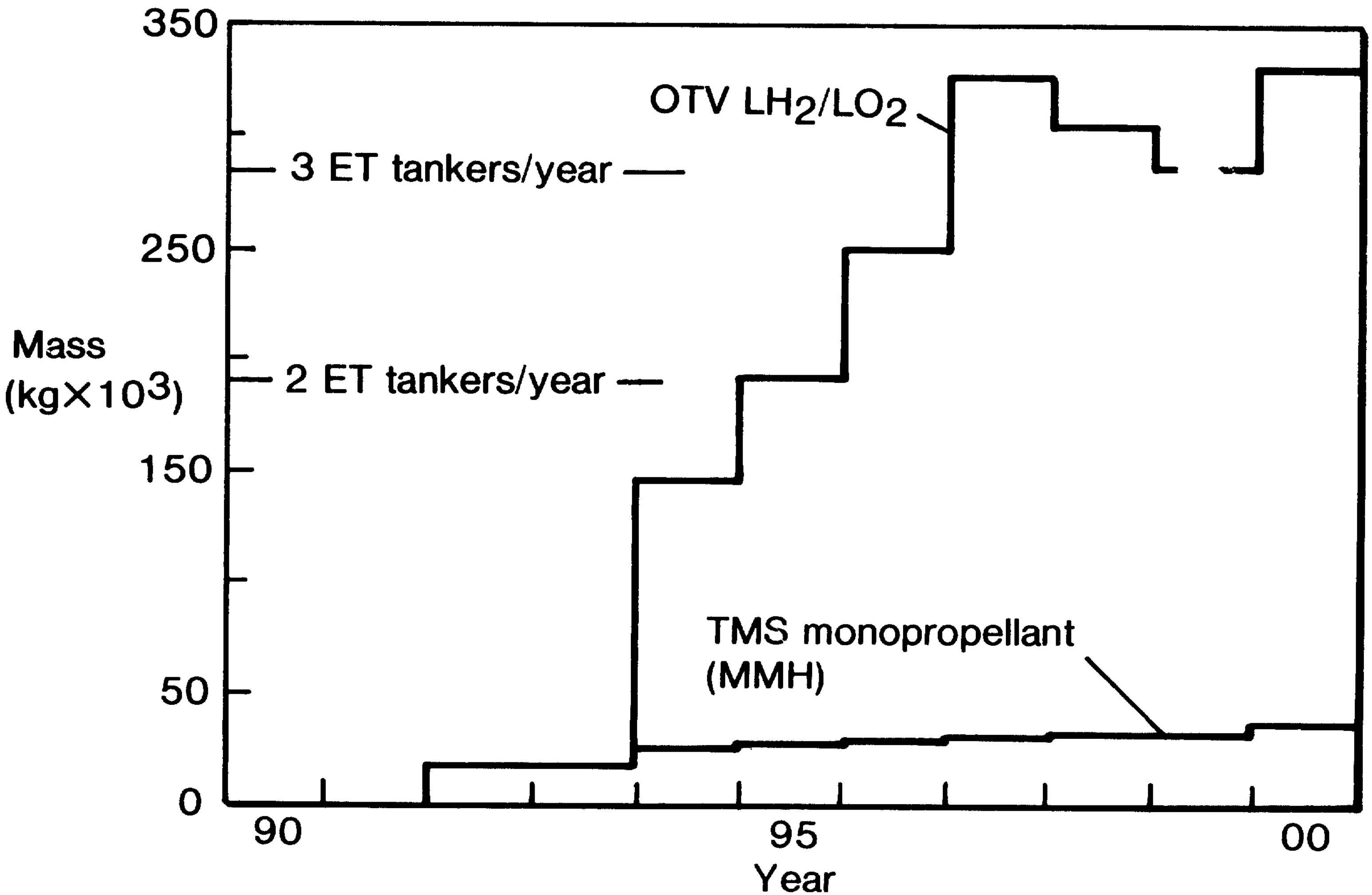
Given an STS traffic model calling for 40 STS missions total from both KSC and VAFB, it seems likely from an extrapolation of the current mission manifest that about 24 missions per year would be accessible from the 28½° Space Station for Honeybee scavanging. This yields a net propellant delivery of just under 280 klb per year. This is less than the first year requirements for the all-up mission model.

Therefore, a supplementary means of delivering OTV propellants would be required sometime within the first two years of operation. Carriage of propellant in dedicated payload bay tankage to the Space Station is a logical possibility. However, by 1997 this would require an additional 7 shuttle missions just for propellant delivery.

The ET Tanker offers a more plausible means of propellant delivery which is capable of meeting the entire requirement without the added complexity of scavanging concepts and with minimal impact on the STS launch schedule. Only 2-3 tankers a year will meet the entire requirement and not impose a great burden on the KSC launch facilities.

The figure also shows propellant requirements for the TMS by year. Assumed propellant usage for each flight is 70% (of the 5000 lb total capacity), a conservative estimate for this application which illustrates the probable upper limit for TMS propellant usage. Nominal propellant usage for the given mission set is 15-30% lower, the use of a conservative propellant usage factor drives out delivery requirements. Scavanging of the Orbiter OMS and RCS tankage is the most economical procedure for supplying storable propellants, in particular MMH, to the Space Station for its operations. Additional safety and reliability concerns with separate propellant tanks in the orbiter are eliminated. The average number of scavanging operations required per year is 10. This is well within the average number of flights, about 18, required for station logistics and payload delivery for the OTV.

28.5-DEG SPACE STATION RESOURCE REQUIREMENTS
OTV/TMS Propellant Needs



30033258-182

As shown on the previous charts, several of the basic required capabilities of the Space Station, such as power and habital volume, increase by approximately a factor of three over the station's 10 year evolutionary development period. To enable cost effective implementation of this magnitude of growth, careful attention must be paid to the initial design to assure that the basic systems are sized to accommodate the required modular additions.

The high level of power required, as indicated by our study, is of significant concern. While some reduction in the required power level can surely be achieved through experiment time lining, etc., there are activities, such as the CELSS, and materials processing which, if implemented on the station, will be major power consumers. A more detailed review of the power situation is required before a final decision on the type of system required can be made, however, use of solar concentrator type arrays and AC power distribution systems appears to be appropriate.

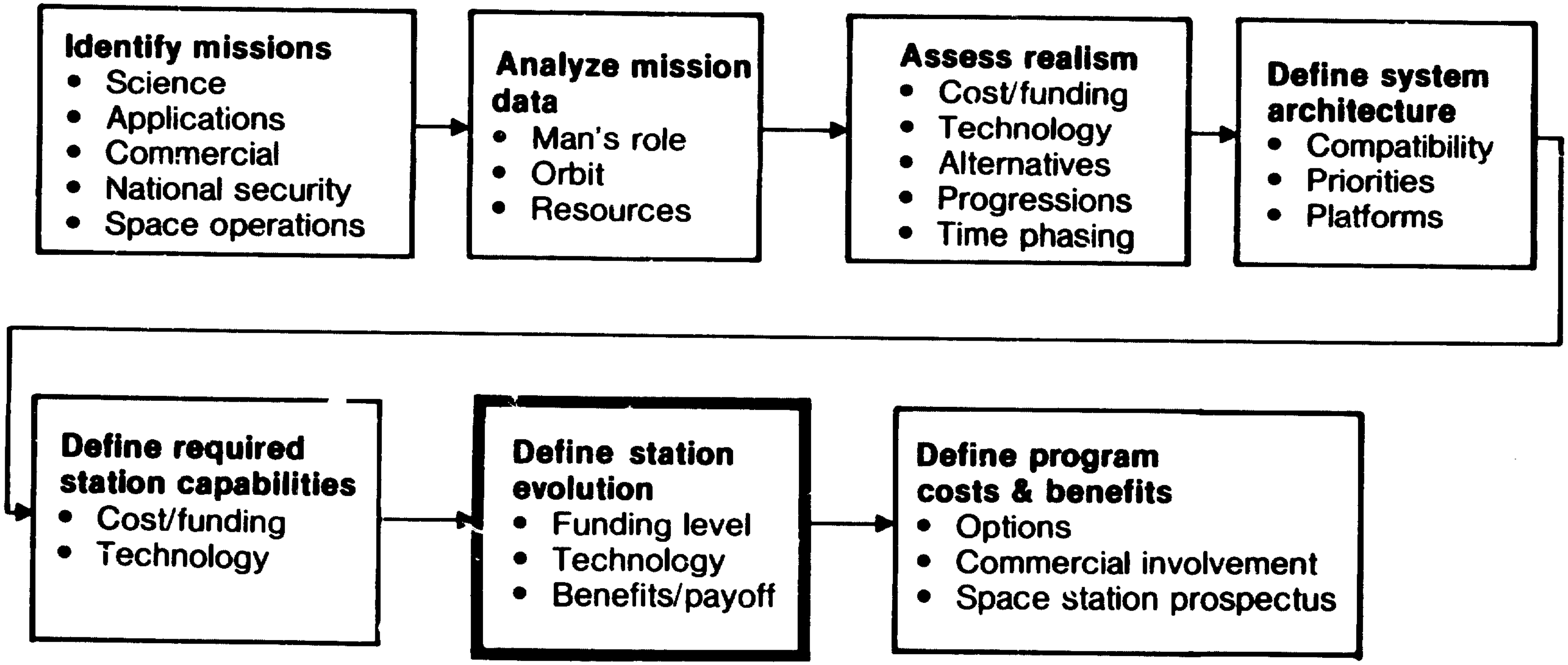
With regard to required data rates, our study shows that the cumulative requirements of all missions can be accommodated through the present TDRS system.

SUMMARY OF REQUIRED CAPABILITIES

- Power, habitable volume & crew size requirements increase by factor of 3 over the decade, indicating basic need for modular design
- Assuming material processing activities remain on station in production phase, power generation requirements become very high when energy storage requirement is included
- Data rates are generally TDRS compatible

The appropriate evolution of the 28.5° station from IOC to its full capability, in compliance with mission requirements, was defined in the next portion of our study. The results of this activity are outlined in the next section.

SPACE STATION STUDY LOGIC



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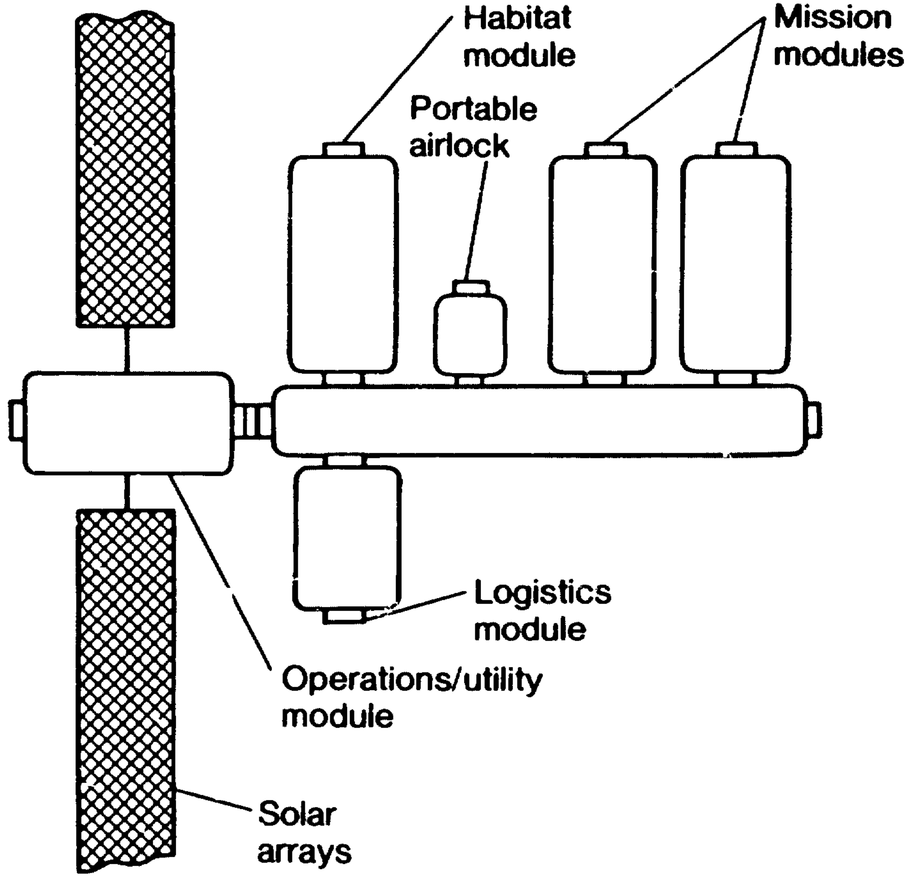
The following three charts show the evolution of the 28.5° Space Station over the next decade.

The 1990 configured station consists of an operations/utility module logistic module, habitat module, 2 mission (experiment) modules, and a portable airlock. This configuration will accommodate the mission set through the initial 2 years of operation.

EARLY ARCHITECTURE
1990



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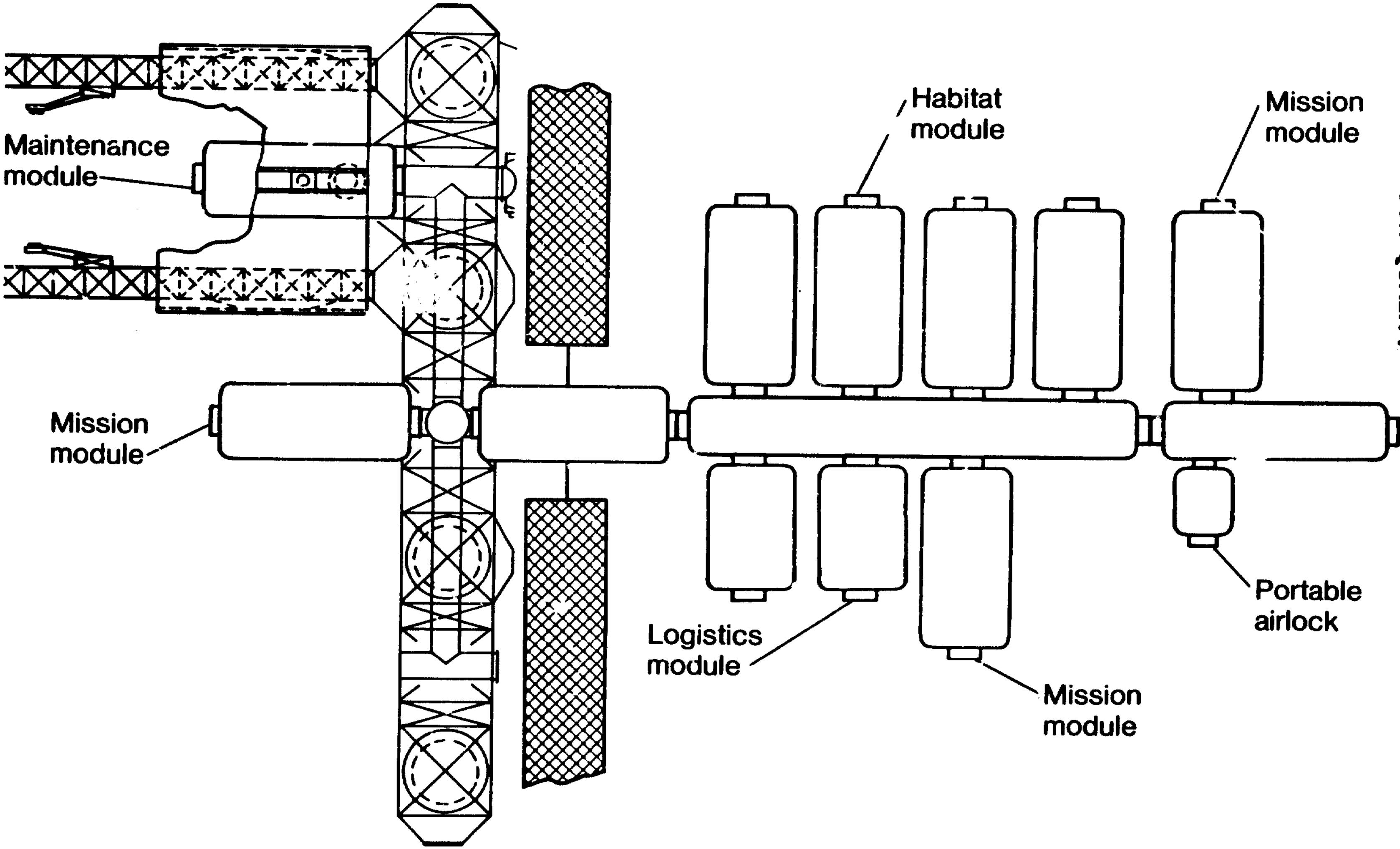
The initial RD&P Space Station configuration is augmented with additional capability starting in 1992. Over a 4 year period, three additional mission (experiment) modules are added as well as additional habitat and logistic modules.

The initial servicing capability is also added to the station during this period. A TMS satellite servicing capability is added first, followed by the first operational OTV launch capability in 1994. The necessary technology development activities leading to this operational OTV launch capability will have been developed over the previous three years.

INTERMEDIATE ARCHITECTURE
1995



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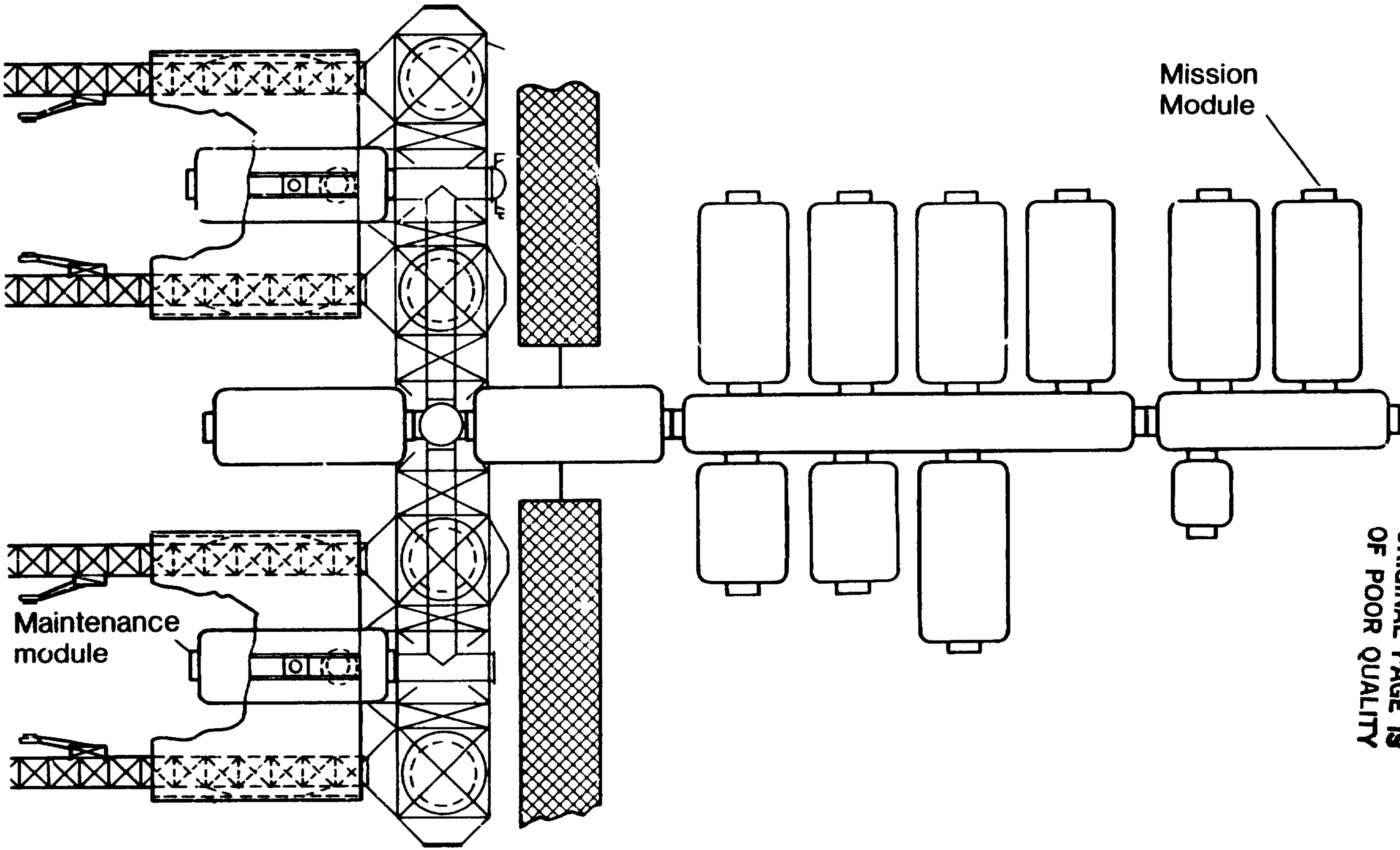
The final growth period within the decade consists of the addition of one mission (experiment) module and a second OTV launch and maintenance facility in 1996. In this configuration the Space Station can accommodate the full set of missions as foreseen for this time period and can also provide the OTV capability to meet the requirements of the free flyer mission model discussed earlier.

LATE ARCHITECTURE
1998

GENERAL DYNAMICS
Convair Division



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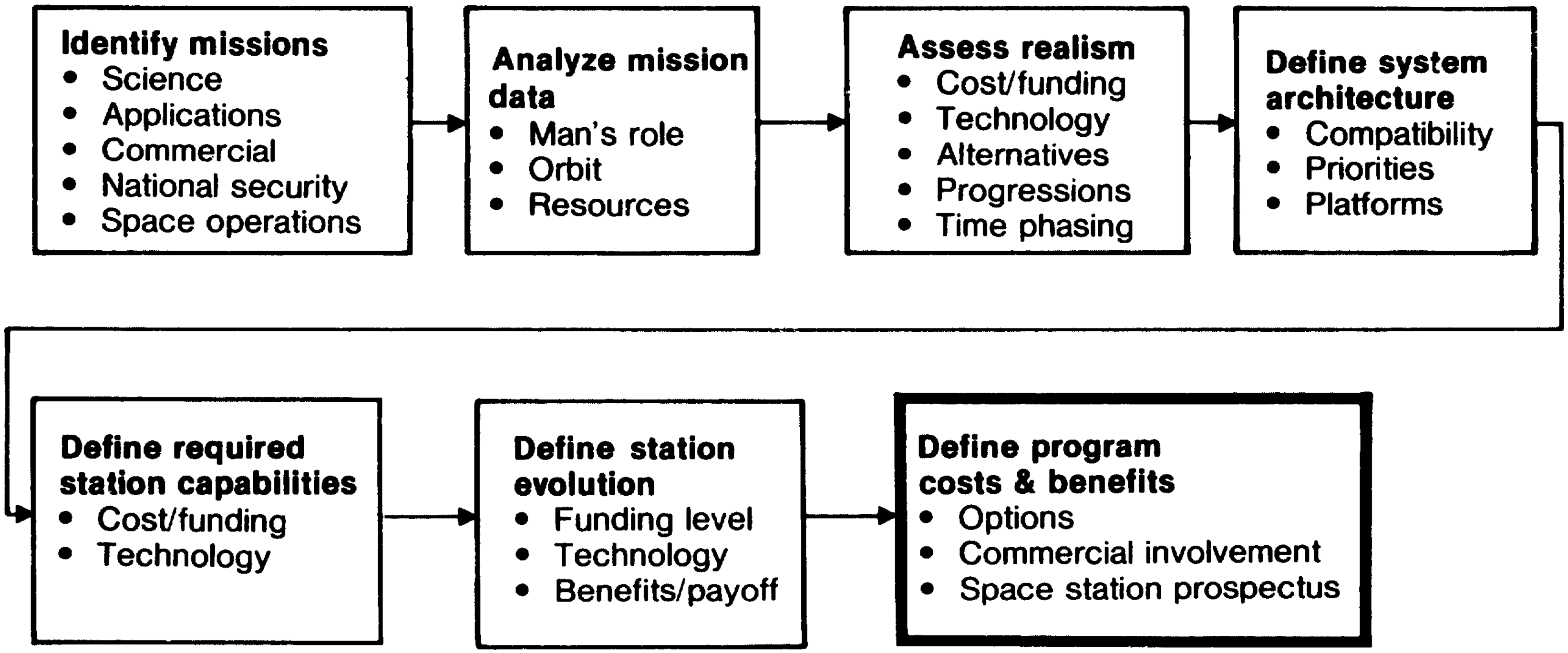
The final major activity of our study dealt with the definition of Space Station program costs and schedules and the quantification of economic benefits of the station. In addition a "Space Station Prospectus" was developed which outlines an approach to private investment in the Space Station development. These activities and the major results obtained are outlined in the next section.

SPACE STATION STUDY LOGIC



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The cost and programmatics analysis activities addressed three principal areas. These are 1) the economic benefits associated with the Space Station, 2) the life cycle cost comparison of architectural and evolutionary options, and 3) potential business opportunity assessment of alternate approach to financing, developing, marketing and operations of the Space Station. Since this study addresses requirements and architecture and not configurations, a parametric approach was adopted for all economic and cost analysis. This permits the identification of cost drivers, sensitivities, relative program costs and funding profiles for comparative purposes and to establish a general understanding of the implications of each option.

TASK OBJECTIVES & APPROACH

Economic benefits

- Parametric analysis of significant cost elements of alternative approaches & identification of cost drivers & sensitivities
  - Research & production
  - Space-based OTV
  - Satellite servicing

Programmatic comparisons

- Generate alternate program costs with a parametric cost model (element level) & a phased funding model
  - Mission payload costs
  - Architectural options
  - Evolutionary options

Business opportunity assessment

- Examine alternate approaches to industry involvement for financing, developing, marketing & operation of space station
  - Business assessment (space station prospectus)
  - Government/industry options (i.e., SDC)
  - User charges

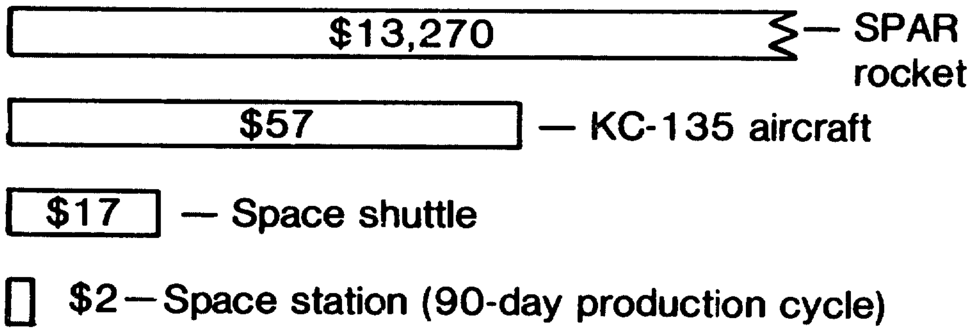
Economic benefits of Research and Production are relatively difficult to quantify. The "cost-per-kilogram hour" function provides one means of evaluating these benefits, based on two important factors: payload capability and mission duration. For Materials Processing in Space (MPS), the Space Station can operate on a 90-day production cycle for about $2.00 per kilogram-hour, as opposed to $17/kg-hr for the Space Shuttle, and much higher costs for other means of performing MPS.

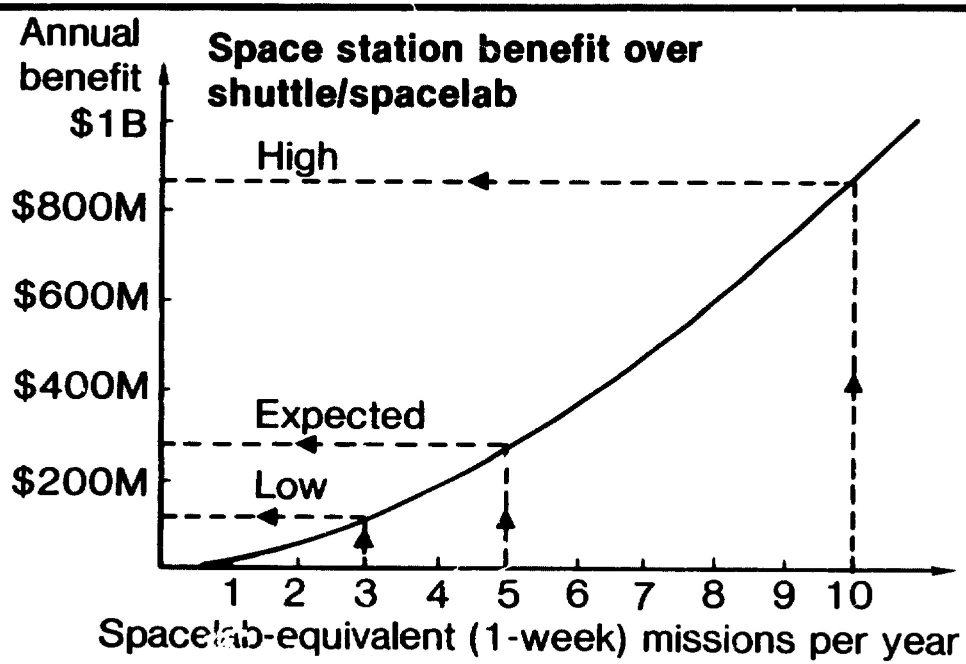
In a more general comparison of Space Station operating costs with the costs of performing Shuttle-Spacelab missions, the Space Station is shown to have an expected annual benefit of $285 million, based on reductions in transportation costs made possible by permanent basing of Spacelab facilities in orbit. Cost advantage of the Space Station over Shuttle-Spacelab increases at higher rates of utilization than the baseline 5 Spacelab-equivalent (1-week) missions per year.

Long-term economic benefits of research and production, although presently impossible to quantify, are great. MPS could evolve into a multi-billion dollar industry, and form the basis for the establishment of a permanent industrial base in space, using non-terrestrial sources (e.g. the Moon, asteroids) for raw materials. Long-term projects with economic potential include solar power satellites, communications platforms (which could permit such developments as "wristwatch telephones"), and permanent space settlements. All of these projects would benefit substantially from the establishment of a Space Station in LEO.

ECONOMIC BENEFITS: RESEARCH & PRODUCTION

Cost per kilogram-hour for materials processing in space





Space station research & production

- Research & production has great long-term potential, but near-term economic benefits are difficult to quantify
- Greatest economic benefits in
  - Materials processing in space
  - Life sciences
  - Astrophysics
- Expected anuual benefit
  - 1990-2000: $285 million
  - 2000+: Potentially very large
- Evolution to permanent industrial base in space, utilizing non-terrestrial sources for raw materials

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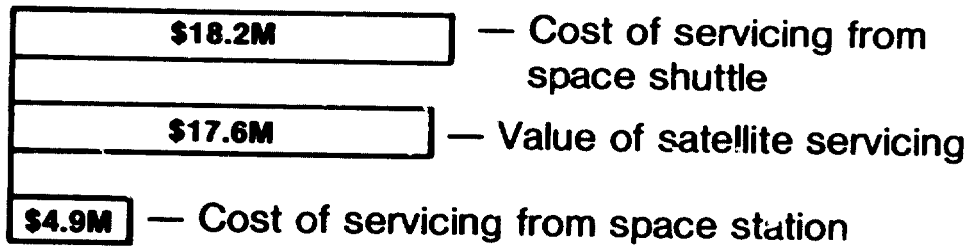
Based on such factors as satellite value, reliability, and the effectiveness of satellite servicing missions, the average value of a satellite servicing mission during the Space Station era is estimated at $17.6 million. Servicing from the Space Shuttle would not be cost-effective in many cases, because the average cost of a servicing mission from the Shuttle is estimated at $18.2 million. Permanent basing of the teleoperator maneuvering system (TMS) and accessories in space, however, reduces the average cost per servicing mission to under $5 million, making satellite servicing from the Space Station economically attractive. An estimated 20 servicing missions per year gives a projected annual benefit of $240 million.

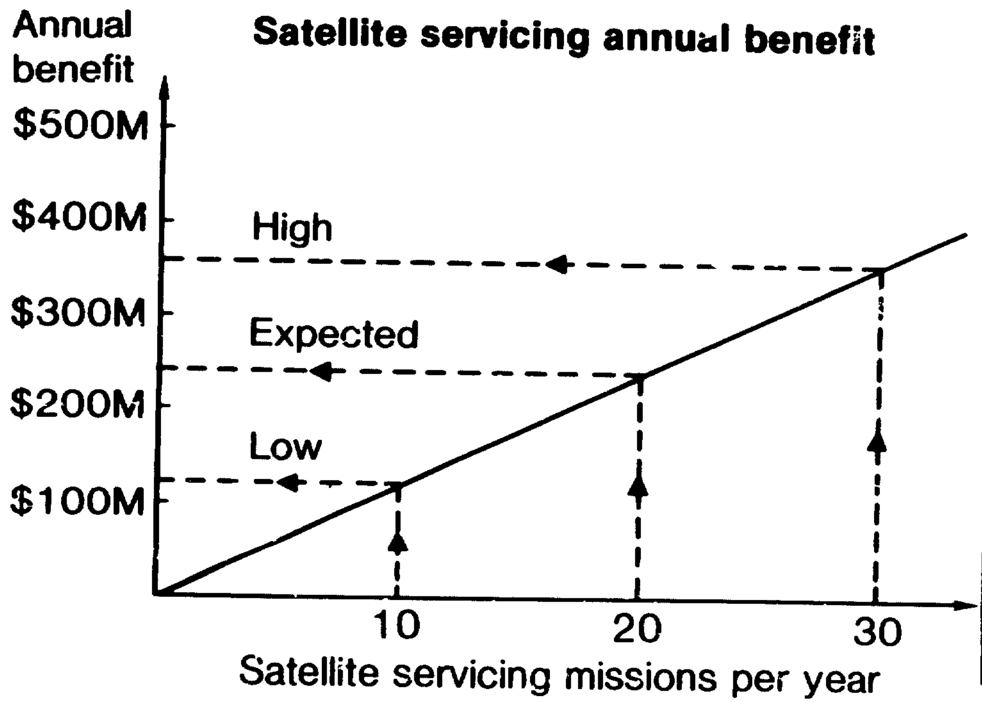
ECONOMIC BENEFITS: LEO SATELLITE SERVICING

Average satellite servicing cost/value (per mission)*



*Using TMS & unmanned servicing module

Satellite servicing annual benefit



Space station satellite servicing

- Satellite servicing from space station expected to cost 75% less than servicing from space shuttle
- Results of satellite servicing (per mission, average)
  - From shuttle: $600,000 loss
  - From space station: $12 million benefit
- Expected annual benefit: $240 million
- **Conclusions: Space station availability makes satellite servicing a viable proposition**

The space-based OTV represents the greatest quantifiable economic benefit of the Space Station. Cost-per-pound for payload delivery to GEO can be reduced from $20,000-$30,000 with today's expendable upper stages to about $6,000 with the reusable OTV, with the potential for reducing OTV mission costs further (to about $4,000/lb.) by redesigning OTV payloads to minimize the cost of delivering them to LEO with the Space Shuttle. Recovery of propellants from the Shuttle External Tank during STS missions could further enchance the economic attractiveness of the OTV function.

ECONOMIC BENEFITS: SPACE-BASED OTV

Cost-per-pound to geosynchronous orbit

$17,000/lb	PAM-D
$21,000/lb	PAM-DII
$21,000/lb	PAM-A
$30,000/lb	IUS
$9,000/lb	Shuttle/Centaur
$13.000/lb	Shuttle-based OTV
$6,000/lb	Space-based OTV

Space-based OTV

- Greatest quantifiable economic benefit of space station program
- Expected annual benefit of over $1 billion
- Maximizes efficiency of space transportation system
- Maximizing of propellant scaveng-ing from the ET can lead potential-ly to increased benefits of a space-based OTV

Cost of a typical OTV mission, for delivery of a 10,000-pound payload to GEO, is estimated at $62.9 million. Cost of the OTV and delivery of the OTV to LEO are amortized over a large number of flights and hence contribute only $1 million to the cost-per-mission. Cost of delivering the OTV payload to LEO is by far the greatest mission cost factor; $45.4 million estimate is based on the projected need for 24.5 feet of Shuttle cargo bay space for launch of a typical O[illegible] payload (10,000 pounds)to LEO. OTV operations costs of $3 million include $[illegible] million for Space Station crew time for OTV turnaround and operations (200 man-hours at $10,000/hour), $200,000 for ground support (2,000 man-hours at $100/hour), and $750,000 in spares costs per mission. By comparison, likely Space Station era OTV competitors, including the relatively cost-effective Shuttle-Centaur, Transfer Orbit Stage (TOS), and Shuttle-based OTV, average about $125.5 million for the same mission. Projection of 17.3 OTV missions per year is based on an estimated 75% market share of a potential 23 OTV missions per year, and yields an annual economic benefit of over $1 billion.

OTV ECONOMIC BENEFITS ANALYSIS (1984 $)

Cost factor (per 10,000 lb of payload)	Mission Cost	
	OTV	Competitor Average*
Upper stage cost	$0.5M	$17.0M
Upper stage delivery to LEO	$0.5M	$108.5M (includes payload)
Payload delivery to LEO	$45.4M	0
Operations/spares costs	$3.0M	0
Propellant delivery to LEO	$13.5M	0
Total	$62.9M	$125.5M

* PAM-D, PAM-DII, Leasat, PAM-A, Atlas/Centaur, Shuttle/Centaur, TOS, Shuttle-based OTV

Economic benefit per OTV mission = $125.5M − $62.9M = $62.6M

Average number of OTV missions per year (1994-2000) = 17.3

OTV economic benefit per year = $62.6M × 17.3 = $1.08 billion

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Economic benefits of the space-based OTV comprise nearly 70% of the total Space Station benefit, ($1.16 billion figure includes $80 million in propellant recovery benefits, assuming OTV users pay $500/lb for propellant which is recovered or launched via ET Tanker at a cost of about $325/lb), with satellite servicing and research and production functions adding $525 million/year in benefits.

For all three functions, the Space Station missions costs were compared with both the economic value of the mission (when quantifiable) and the projected cost of alternative means for accomplishing the same mission. For conservatism, economic benefits were calculated as the smaller of the two differences (Mission Value minus Space Station Mission Cost, Competitor Mission Cost minus Space Station Mission Cost).

Total quantified benefits of $1.6 billion per year do not include any income or benefits from commercial materials process in space (MPS). Potential economic benefits of MPS, although estimated by some experts to be in the billions of dollars, were not considered firm enough for inclusion in this analysis. Rapid development of MPS technology, however, could increase Space Station benefits substantially.

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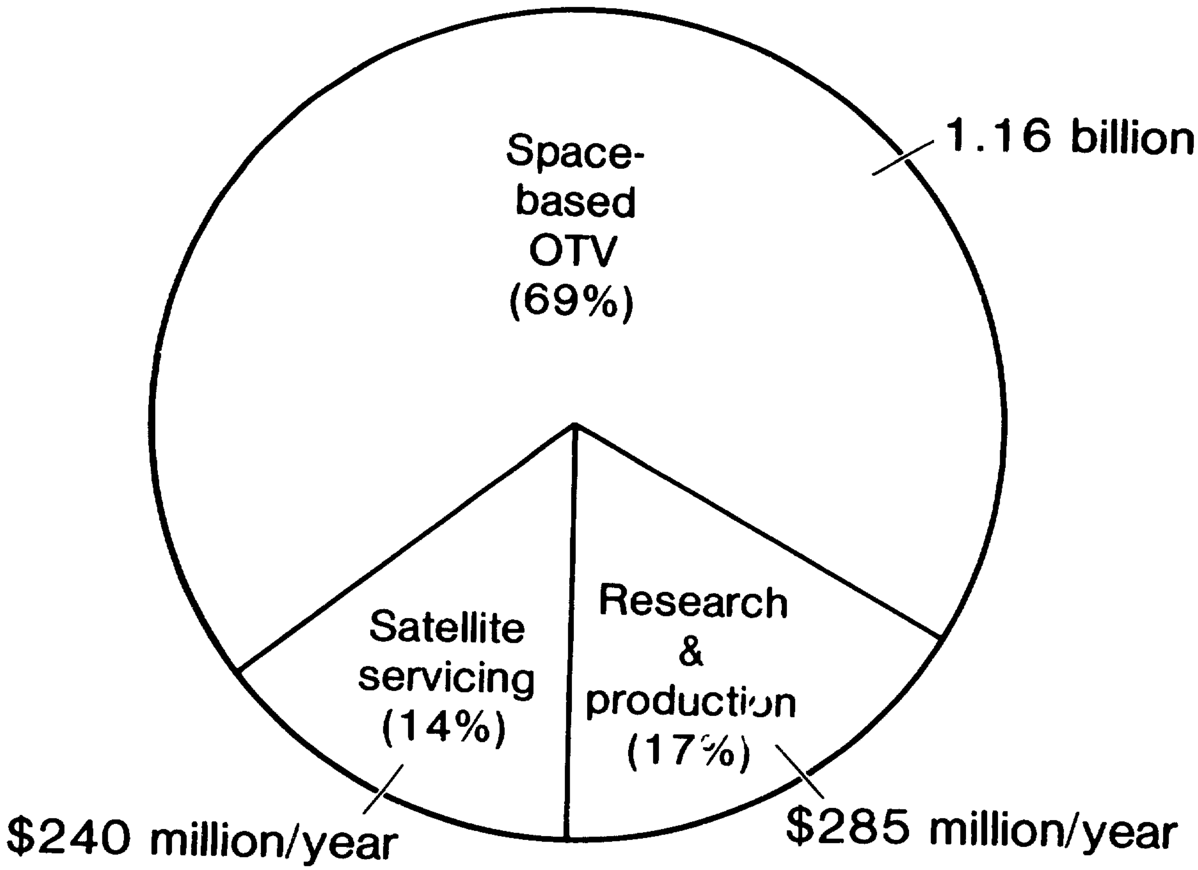
SPACE STATION ECONOMIC BENEFITS
(1984 $)



Total economic benefit: $1.685 billion

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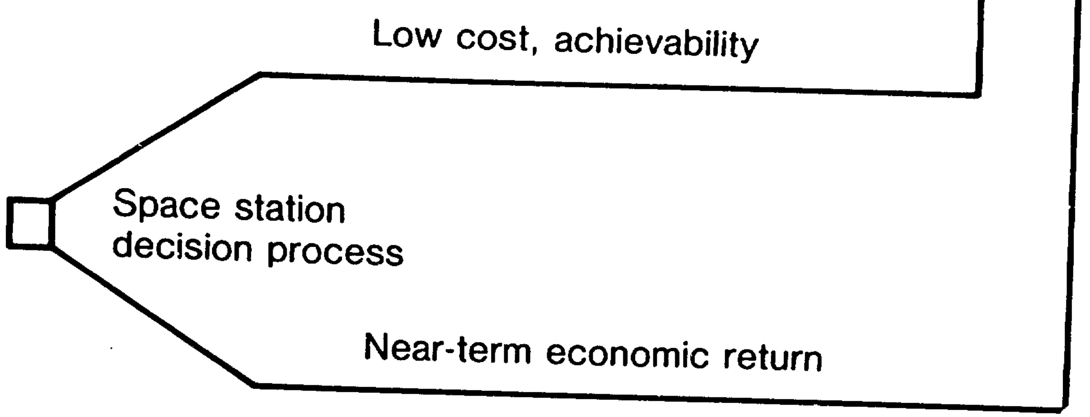
Conventional approaches to Space Station program planning have generally emphasized low cost and technological achievability, which explains the common preference for a relatively modest research and production facility as an initial Space Station. But, although the long-term economic benefits of research and production are high, the greatest potential for rapid economic payback is provided by the space-based OTV function. Hence, if near-term economic return becomes a major program consideration, the OTV function should be established as early as possible, rather than as a later or lower priority development.

IMPACT OF ECONOMIC CONSIDERATIONS ON SPACE STATION DECISION PROCESS

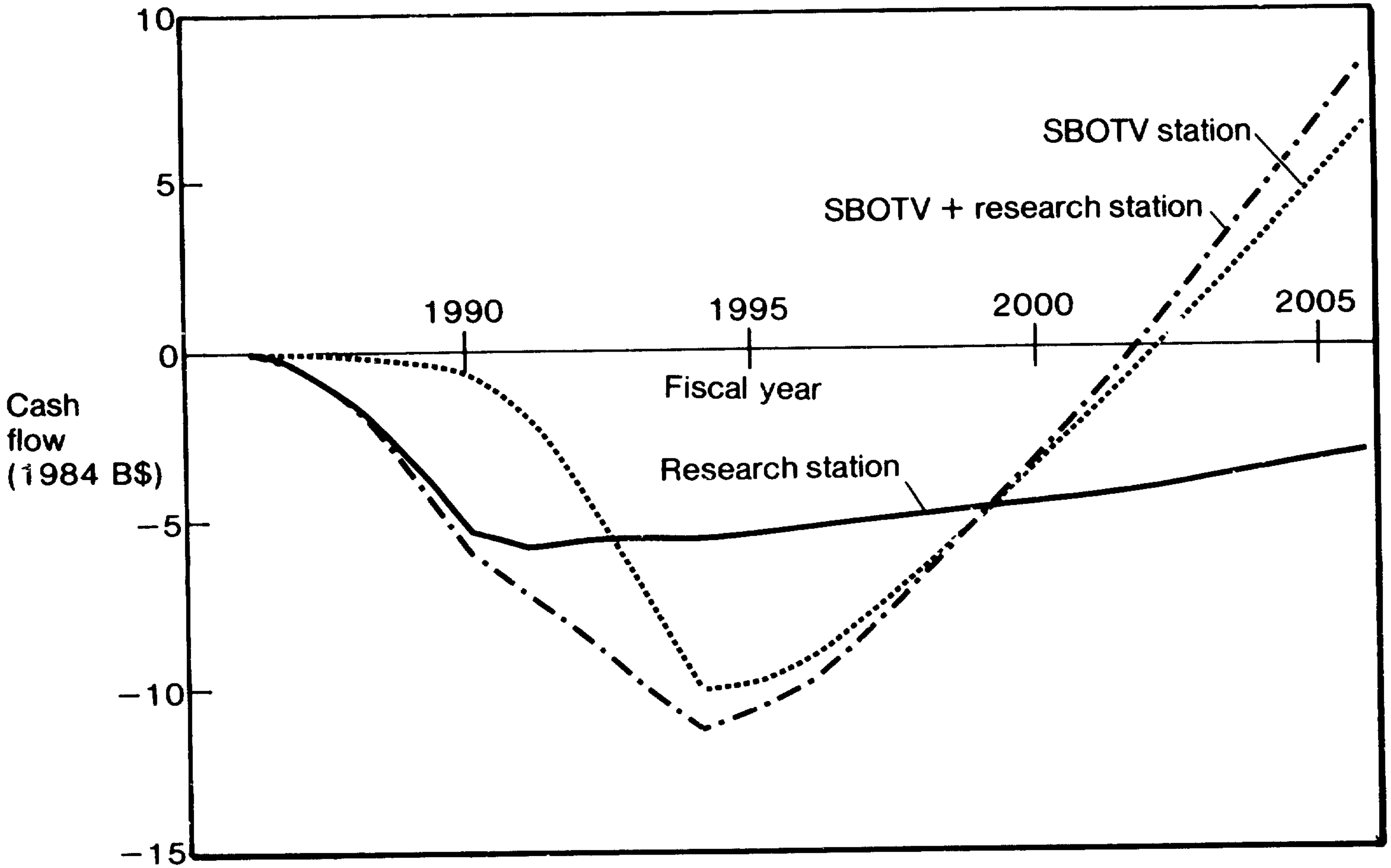
Space station function	Near-term (1990-2000)	Economic Return	Long-term (2000-2050)
Space-based OTV	High		High
Satellite servicing	Med		Med
Research & production	Low		High



Payback period (undiscounted) is 18 years for a dedicated OTV base, 20 years for a combined OTV base/research and production facility, and much longer for a dedicated research and production facility. Investment horizon could be reduced if OTV technology can be developed in fewer than the ten years assumed in the baseline case. Payback period from initiation of OTV operations is only 9 years for a dedicated OTV base, and 11 years for a combined Space Station.

Although these payback periods are relatively long by private industry standards, they do not include the non-economic benefits of the Space Station, nor do they account for the political economic benefits which today are impossible to quantify (e.g., MPS benefits).

ECONOMIC BENEFITS CASH FLOW
Undiscounted



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The program for development of our proposed Space Station system is shown on the facing page. Development schedule for the space facilities, ground facilities and related STS support vehicles is shown. In summary it appears feasible to meet an IOC date of 1990 for the 28.5° RD&P Space Station if Phase B activities are initiated in FY 1984.

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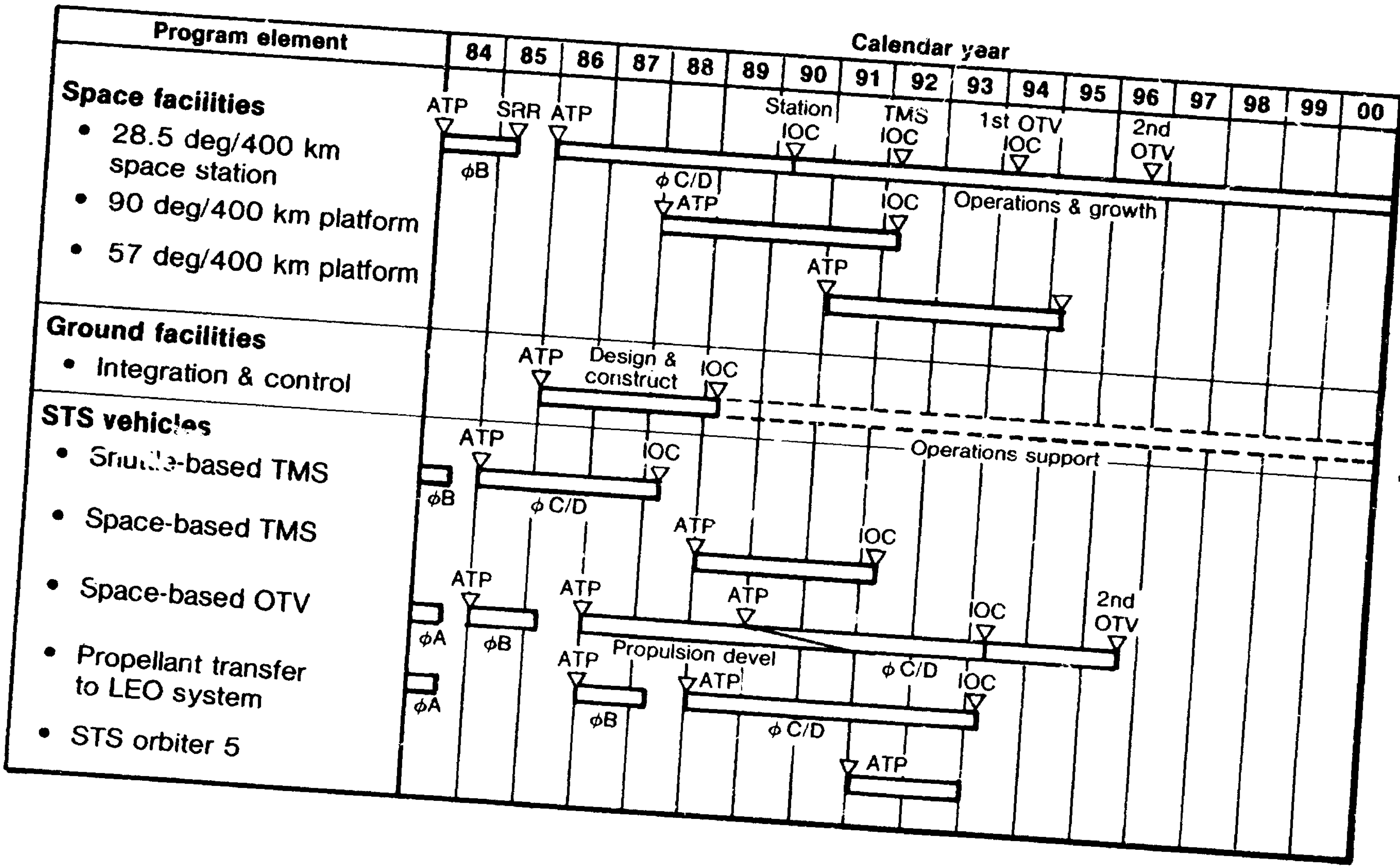
BASELINE SPACE STATION PROGRAM



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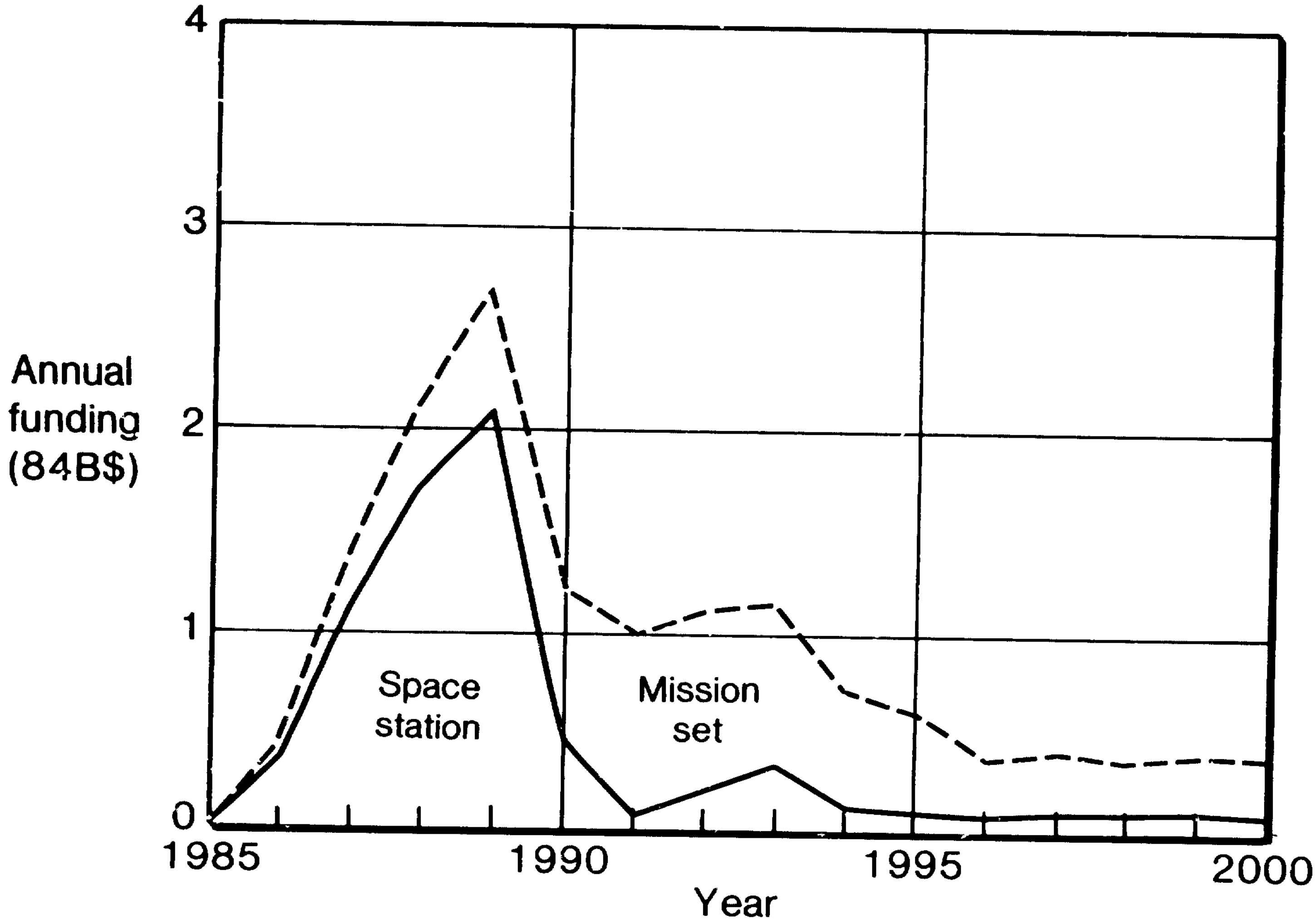
The funding profile for the research development and production station and its mission set is shown on the facing page. A single peak of about $2.7B is encountered midway through the development program aimed at a 1990 IOC. Approximately $5.5B is required to acquire and activate the IOC station with an additional $800M required for the full capability configuration.

RD&P SPACE STATION PROGRAM FUNDING PROFILE



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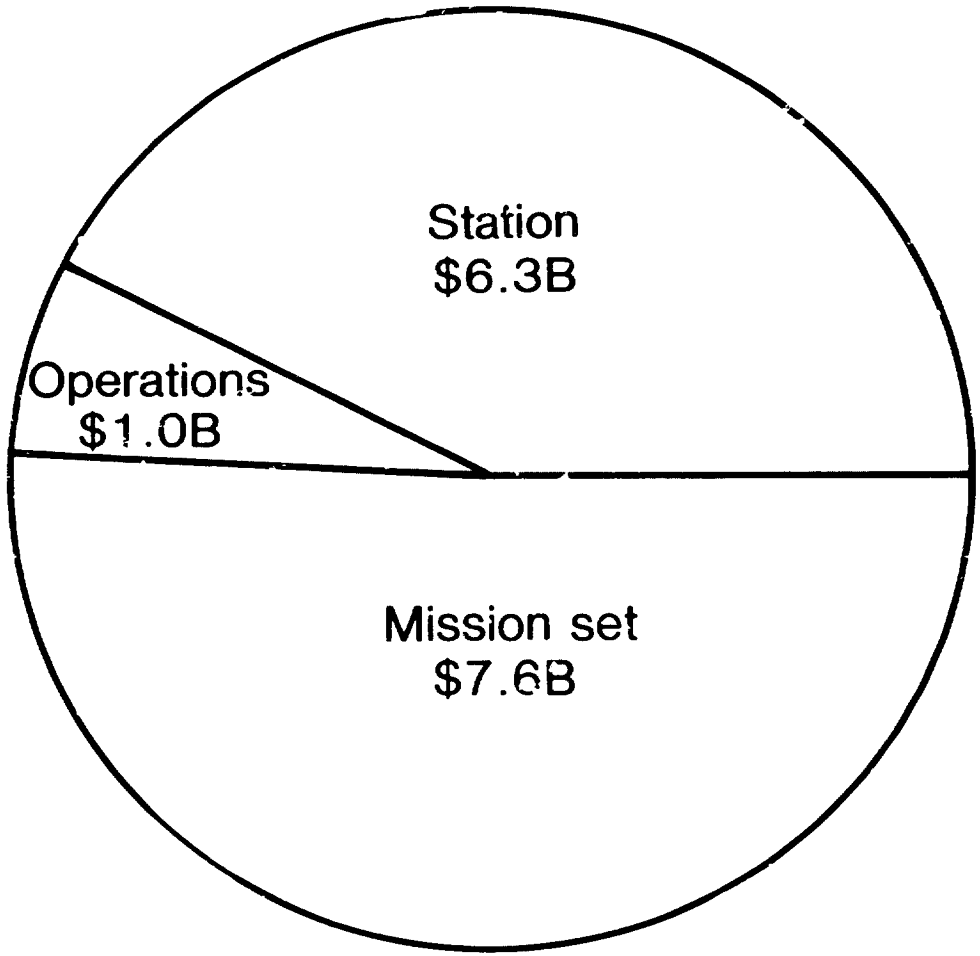
The funding distribution for the RD&P station is shown on the facing page. The mission set cost is $7.6B and includes only those government-funded payloads and experiments specifically associated with the Space Station (Space Station attached payloads) and also includes operations' costs associated with those payloads. Operations' costs associated with the Space Station itself are expected to be about $1B over the period considered.

RD&P SPACE STATION PROGRAM FUNDING DISTRIBUTION

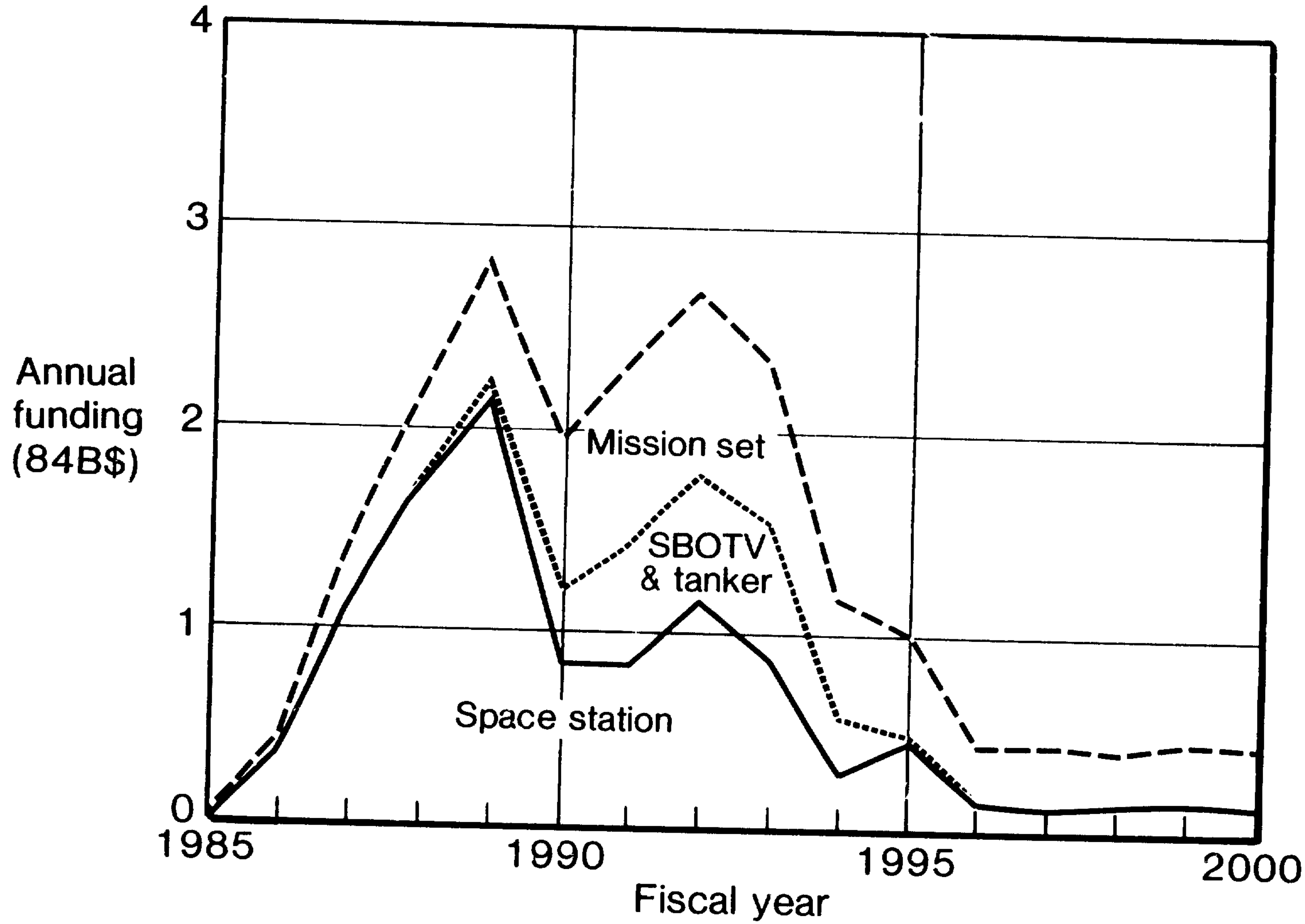


Total $14.9B

30033258-144

The funding profile for the baseline or combined research and operations station and its mission set is shown on the facing page. A double peak of over $2.8B is encountered in the development program aimed at a 1990 IOC for the Research Station and 1994 for the SBOTV operations.

COMBINED RESEARCH & OPERATIONS SPACE STATION PROGRAM FUNDING PROFILE
Recommended Program



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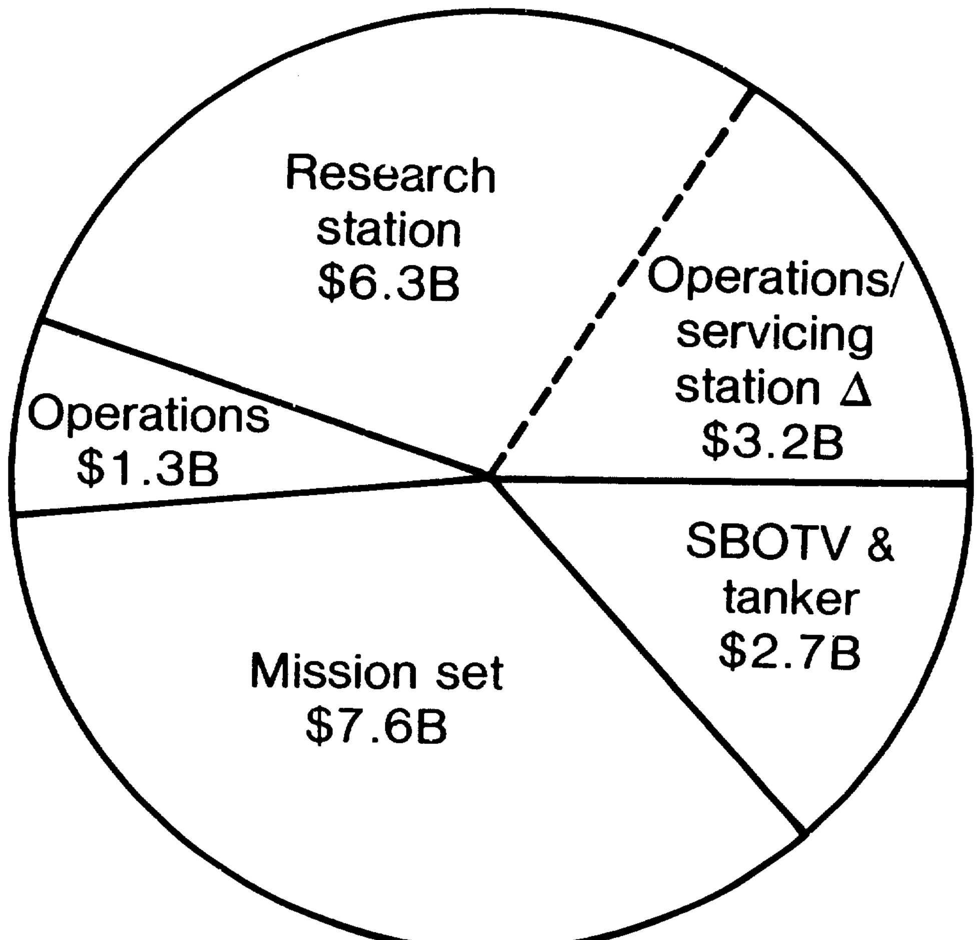
The funding distribution for the combined research and operations station is shown on the facing page. Approximately $6.3B is again required to acquire and activate the Research Station with an additional $3.2B required for the SBOTV operations capability. The mission set cost of $7.6B includes only those government funded payloads and experiments specifically associated with the research Space Station and their operational costs. Operations costs associated with this baseline station itself are expected to be about $1.3B over the period considered.

COMBINED RESEARCH & OPERATIONS SPACE STATION PROGRAM FUNDING DISTRIBUTION

Recommended Program



Total $21.1B

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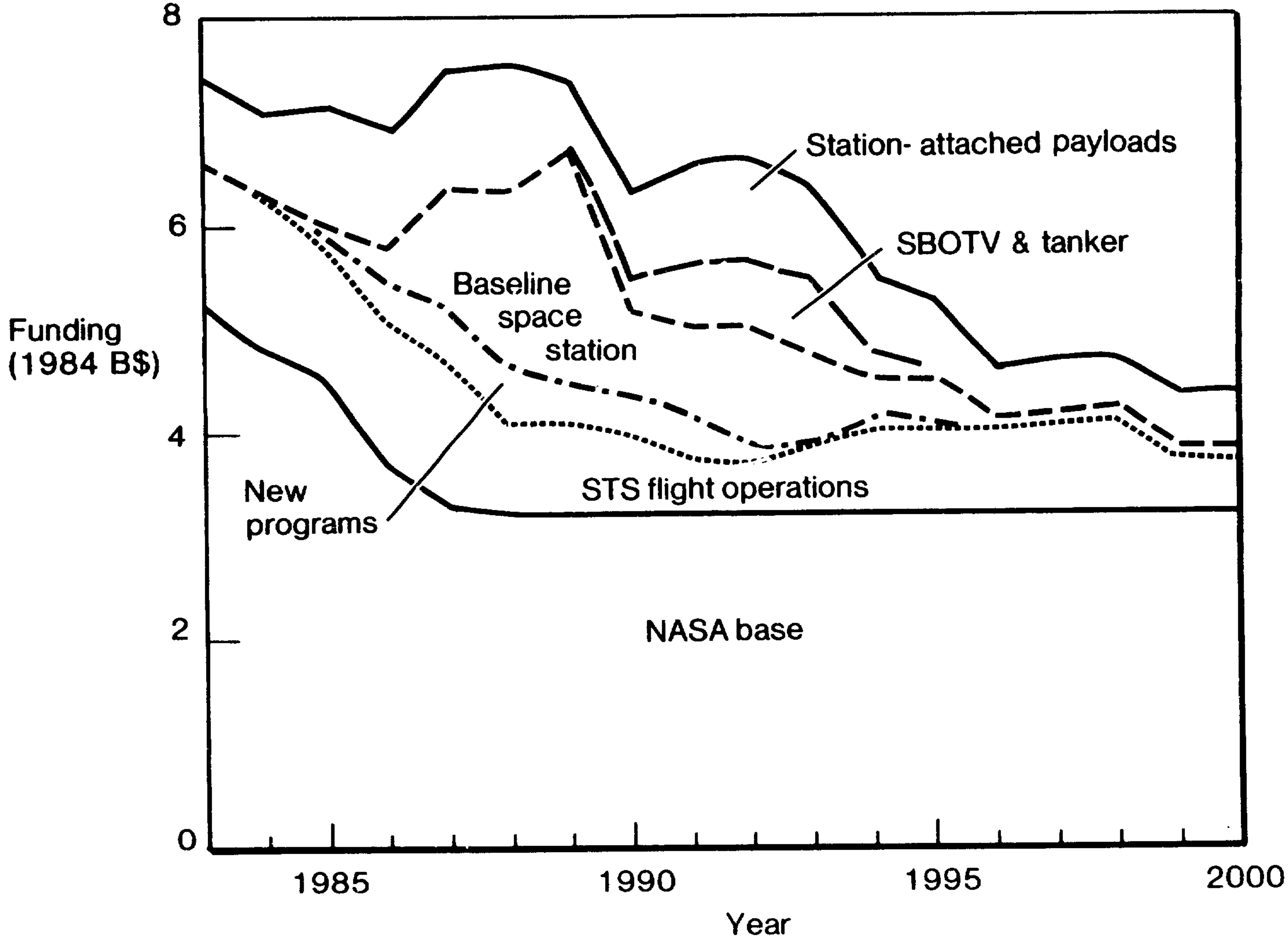
This chart presents the NASA budget requirements for the baseline (combined research and operations) station, the SBOTV and propellant tanker, the Space Station mission payload set, other related programs (TMS, LEO platform, etc.) the STS flight operations and the NASA budget "base". The budget base includes R&PM, construction of facilities, Aeronautical R&D, Tracking and Data Acquisition, STS R&D, etc. As may be seen a peak of about $8B occurs in FY 1989 with the funding requirements dropping in the out years. It is entirely plausible that with only a modest budget growth sufficient funding will be available for a substantial total NASA program.

NASA BUDGET FUNDING REQUIREMENTS COMBINED RESEARCH & OPERATIONS (BASELINE) SPACE STATION PROGRAM



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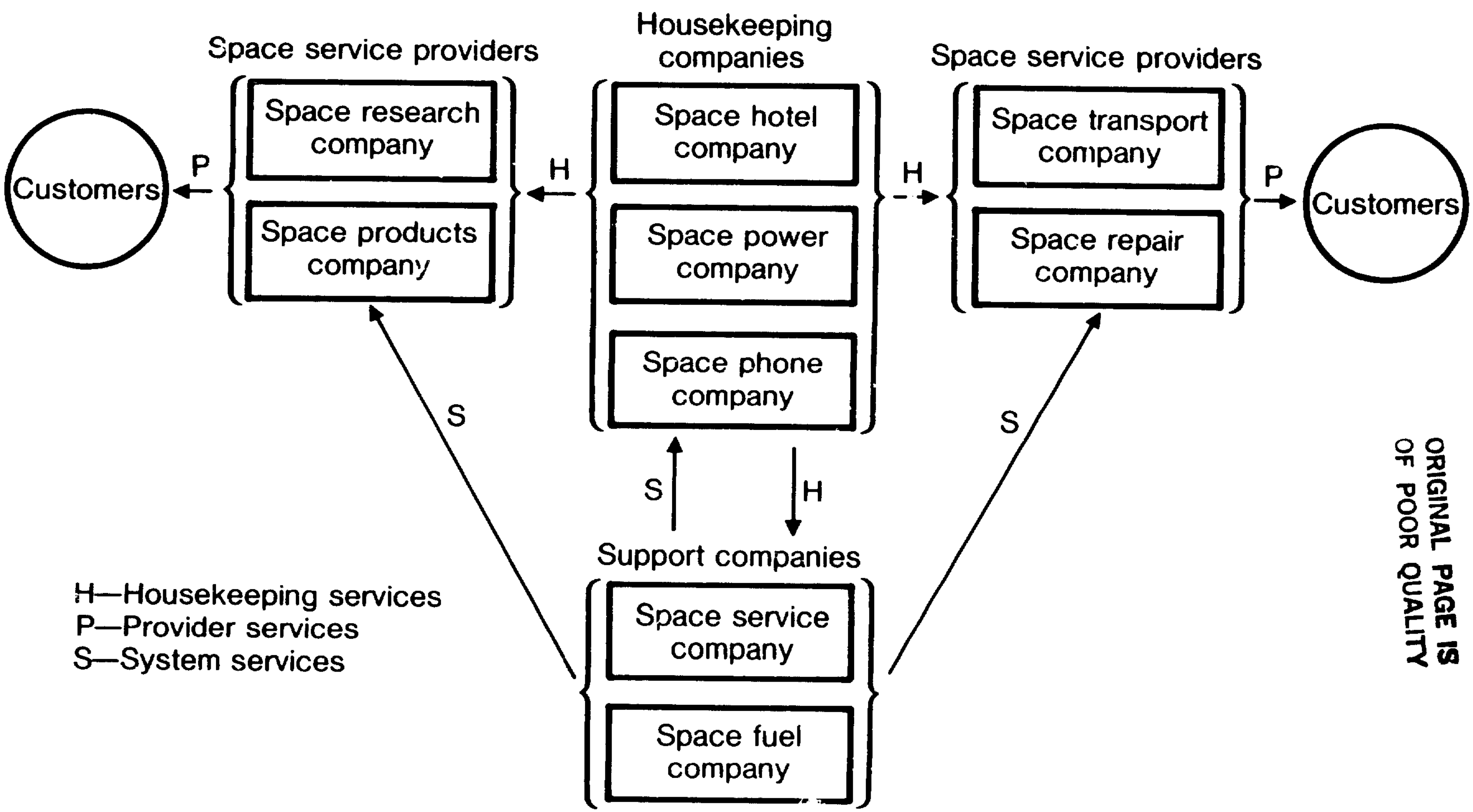
The Space Station Prospectus developed by General Dynamics as a supplement to this study provides an alternate concept for Space Station financing based on a maximum degree of private-sector involvement in such a project. The prospectus is a fictitious stock offering for a hypothetical company, Consolidated Space Enterprises (CSE), which starts and retains partnership in a number of subsidiary Space Station companies, each of which develops a separate Space Station resource. Investment in these companies would be open to interested corporations and the general public, and could substantially reduce government funding requirements.

SPACE STATION PROSPECTUS

- Develops alternate concept for financing a space station program
- Establishes Consolidated Space Enterprises as general partner in ten subsidiary space station companies
- Investment in space station companies open to interested firms & general public
- Government investment in space station development can be substantially reduced
- Seven of ten space station companies appear commercially viable without government financial support

The interaction of the companies described in the Space Station Prospectus is illustrated. Space Service Providers offer services directly to government and industry customers, and are supported by housekeeping companies which provide utility services, and Support Companies which provide maintenance and fuel. One such provider could be Space Transport Company, which would operate the space-based OTV. Space Transport Company could purchase propellants from Space Fuel Company, and lease the OTV part maintained by Space Service Company. A systems integration company, not shown, would prevent operational conflicts among the Space Station companies. Consolidated Space Enterprises would start each company in accordance with the emergence of its market and investor interest, and would remain as general partner in each venture. The companies might individually seek Joint-Endeavor support from NASA for development of each company's facilities.

CONSOLIDATED SPACE ENTERPRISES
Space Station Subsidiaries



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MAJOR STUDY CONCLUSIONS

1. Mission requirements exist that are adequate & representative for station definition

2. From a priority standpoint, the initial space station to be developed should be a joint research, development, production, operations & servicing facility at 28.5-deg inclination (IOC 1990)

3. The mission set does not substantiate the need for a space station in a 57-deg orbit in the 1990s

4. Although earlier requirements do exist, delay of a polar orbit station to at least the end of the next decade is recommended

MAJOR STUDY CONCLUSIONS (continued)

5. Operations & science/application missions can coexist on the same 28.5-deg station

6. A space-based OTV launch capability is the major quantifiable economic justification for a space station ($1.1B per year) — capability should be developed as rapidly as technology allows

7. Cost of the initial recommended space station research, development & production facility is approximately $5.5B at IOC & $6.3B at full capability (1984 $)

8. The space-based OTV function incremental cost is approximately $3.2B (1984 $)

9. Realistic opportunities exist for private investment in space station development — a potential investment scheme is outlined in our "Space Station Prospectus"

Having concluded the initial phase of this Space Station mission requirements study, it seems appropriate to look ahead to the next phase of activities. Some of the major conclusions of our study are reiterated on the facing page, but as a particular point, we would like to focus on one potential approach which could lead to an early, affordable, effective way to start the Space Station program. It is recognized that the approach discussed on the following charts, which utilizes a "STS platform" is one of many potential schemes which could be developed for this purpose. In this regard, we at General Dyanmics have also investigated several schemes, and consider that the approach defined herein warrants further study.

SPACE STATION PROGRAM OBSERVATIONS

- Mission requirements overwhelmingly support the need for a space station
- A single space station is the way to begin
- The space station must evolve its capability
- OTV aspect of space station study uncovered significant economic benefit
- We need an early, affordable, effective way to start the space station program

As a first step towards development of the "STS platform" concept, the wings, tail, crew compartment, and the TPS are removed from the Orbiter. The cargo bay is stretched by approximately 30 feet, and a forward control module is added.

A forward fairing for a solar power array, and a wraparound heat exchanger are added to the external tank. Access provisions to the hydrogen tank are added.

The solid rocket boosters remain essentially unchanged from their present configuration.

The above items comprise the basic elements of the "STS platform".

THE STS AS A RESOURCE FOR EARLY SPACE STATION CAPABILITY

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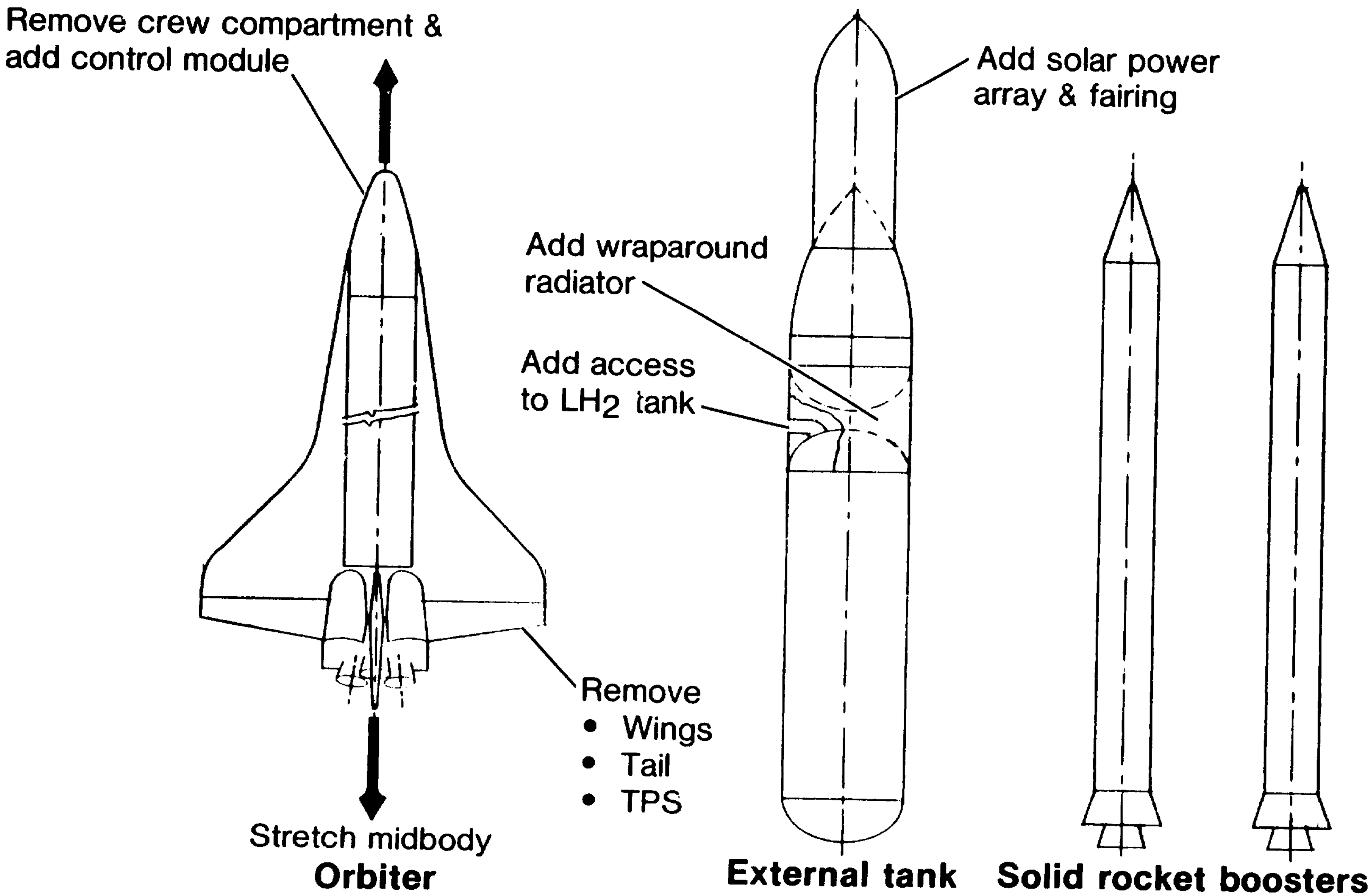

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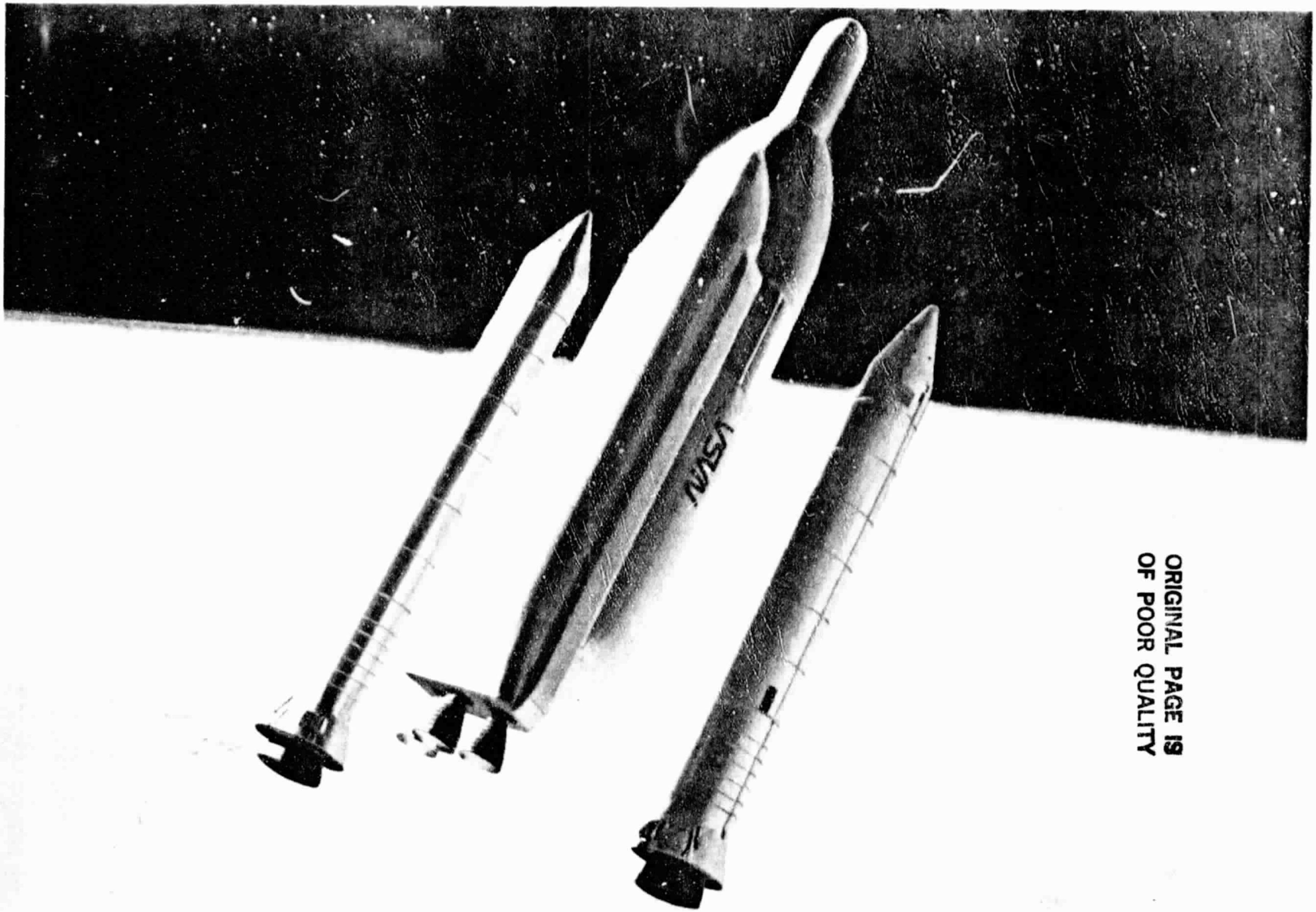
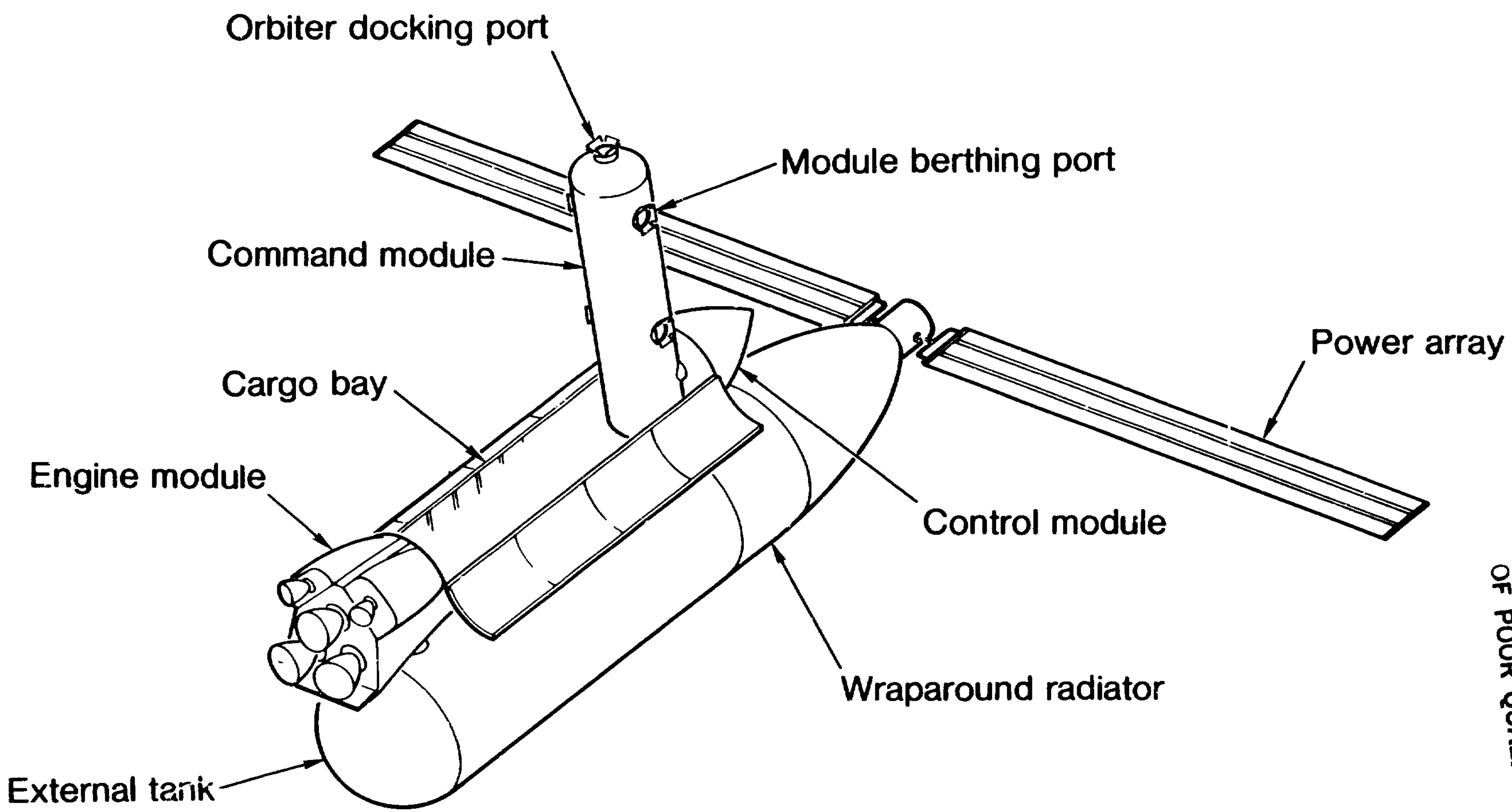
The STS platform is launched, unmanned, with nearly normal staging of STS elements. During ascent, the fairings that cover the solar power array are jettisoned. The STS platform is finally positioned in its desired orbit.


NASA

Once on orbit, the cargo bay doors are opened automatically and the platform command module is rotated 90° from its stowed position in the cargo bay to its operating position. With the command module in this position, an Orbiter cargo bay equivalent length remains available for accommodating spacecraft, etc., delivered by the Shuttle.

The external tank remains attached to the platform for later use since it potentially can serve many useful functions as a part of the station.

PROFILE OF STS PLATFORM



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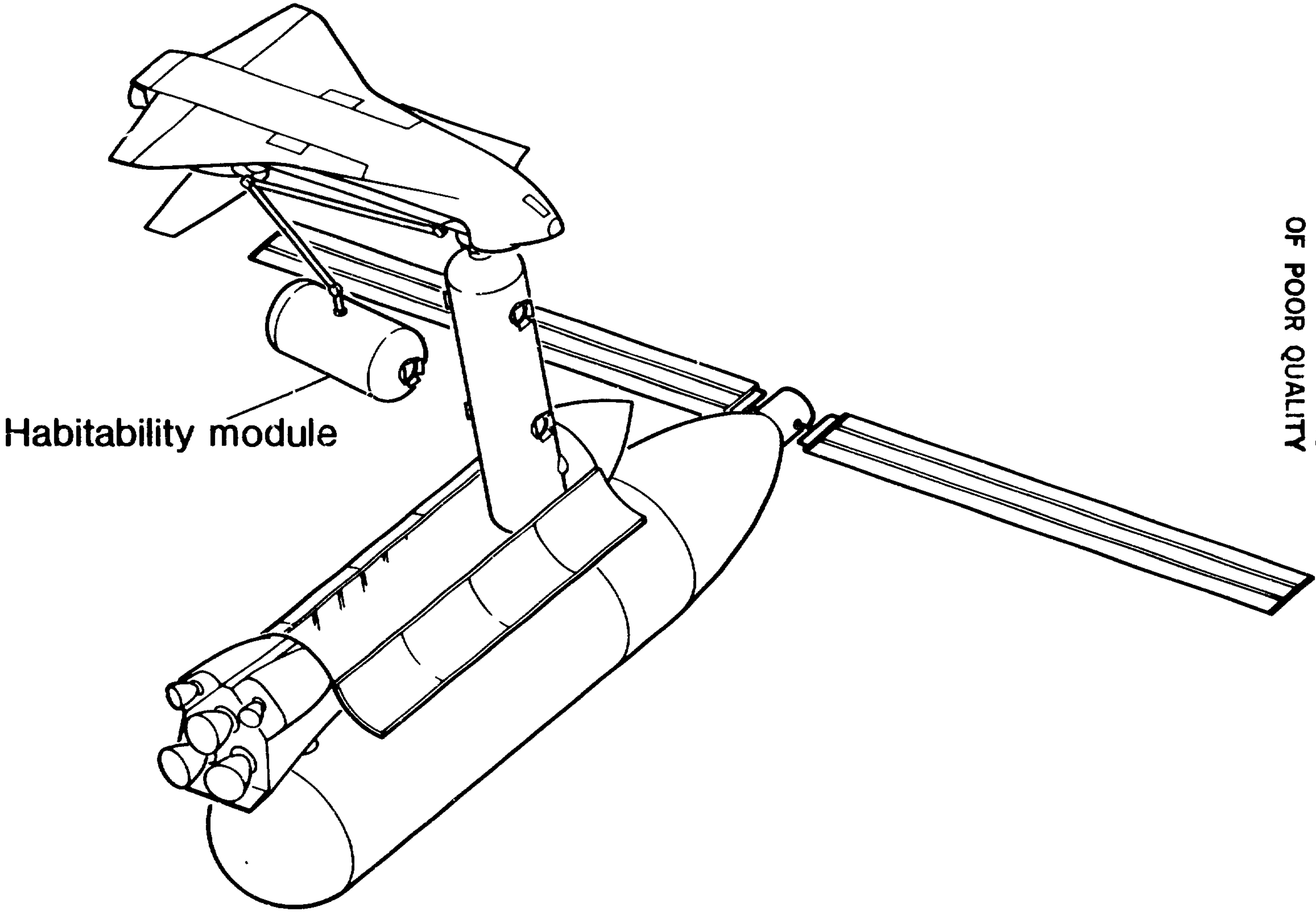
The crew can be installed on the first Orbiter flight to the STS platform. The flight could carry one or two modules, such as habitability module and a logistics module. They would be coupled to ports that exist on the command module. With the crew aboard, we have a permanent Space Station capability achieved in two flights, with an immediate capacity to perform many tasks.

FIRST FLIGHT TO PLATFORM INSTALLS HABITABILITY MODULE FOR CREW



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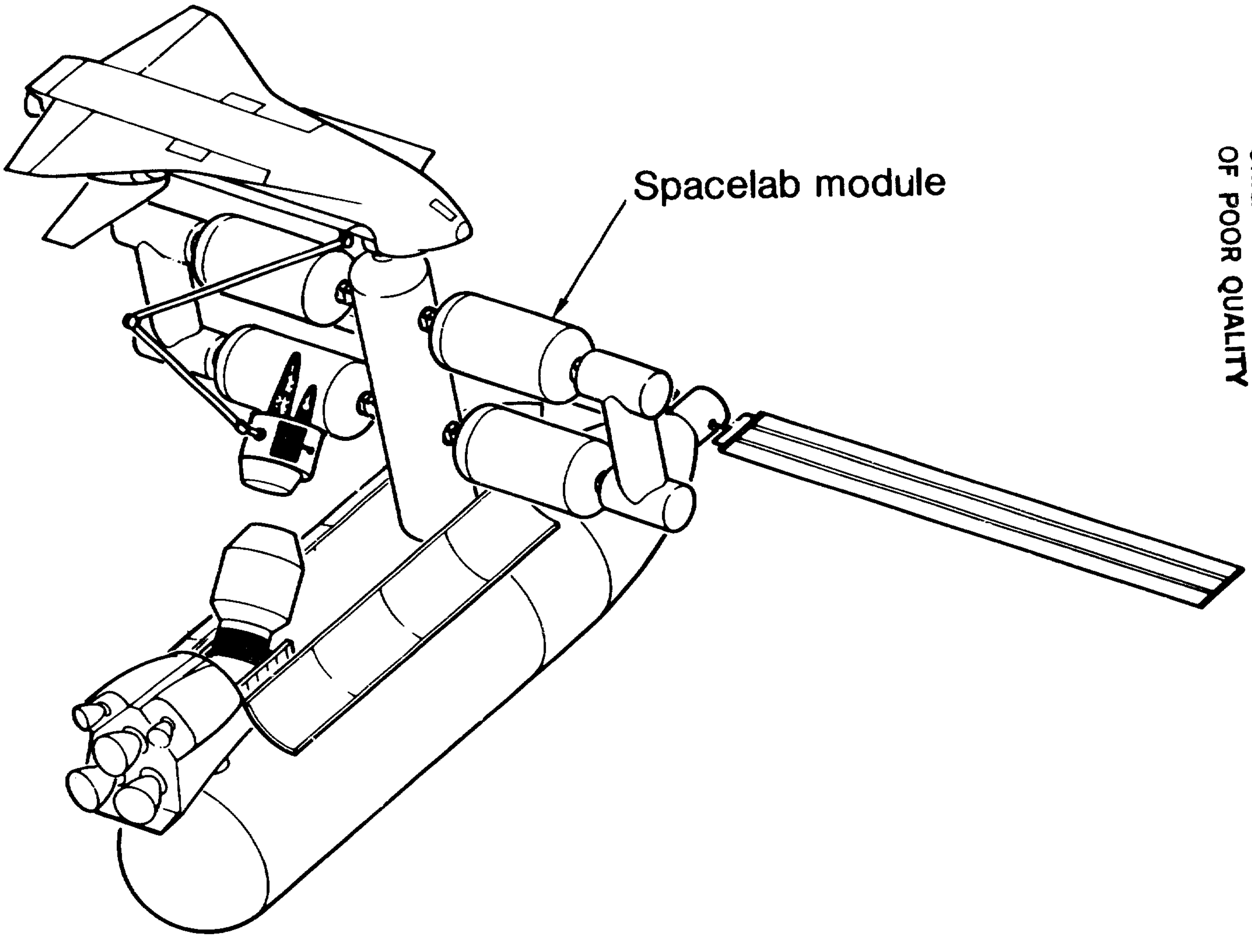
The presence of a cargo bay as part of an early Space Station provides for an easy transition from Orbiter-based activities to Station-based, and may provide the opportunity to conduct important technology development missions without a major shift in approach from Orbiter-based experiments to space-based.

As an example, technology development related to space-based OTV operations from the Station can be carried out with a minimum of change. Since the same relative arrangement is preserved between the Orbiter and the Station in this concept, we have the basis for early experimentation in servicing and perhaps even in carrying out OTV flights from the Space Station.

TECHNOLOGY DEVELOPMENT FOR SPACE STATION



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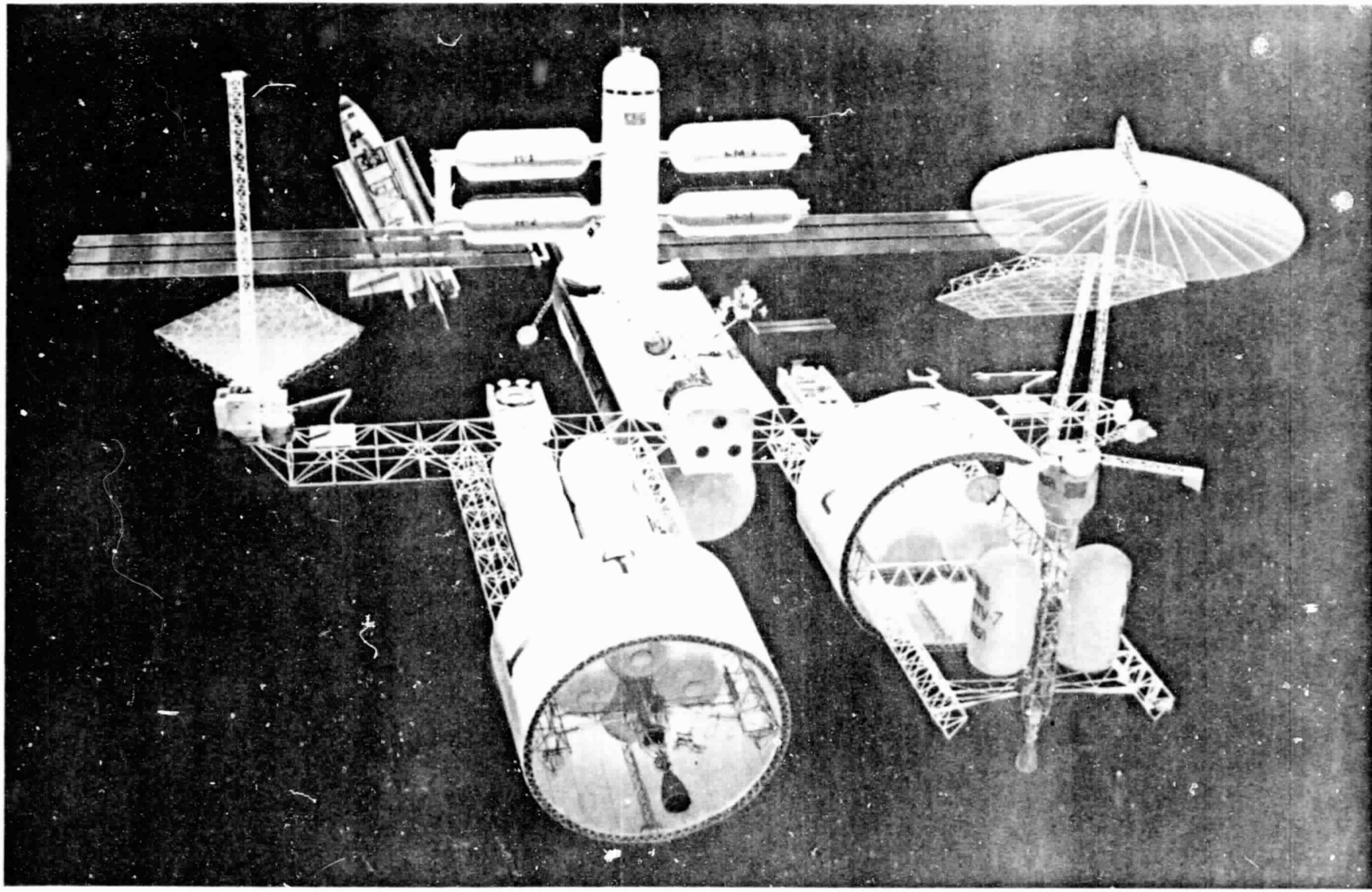
In this concept, we move progressively from technology development to full operational capability. The facing page shows two OTV servicing stations, with spacecraft flight preparations in progress, in addition to the RD&P modules installed earlier. The original STS platform remains the backbone of the Space Station, nothing becomes obsolete. The cargo bay, for example, having been used initially for technology development missions, is now diverted to other purposes, such as a base for teleoperators.

In summary, we at General Dynamics recognize our mutual need to find the right way to start the Space Station program. We suggest that early and serious consideration be given to the STS platform approach. Finding ways to reduce the cost of achieving a Space Station is the key to success. We see within the STS the technology resource and physical means that can make the initial Space Station possible.



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